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ENHANDED BATTLE DYNAMICS FOR THE
FORCE EVALUATION MODEL

by

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ENHANCED BATTLE DYNAMICS FOR THE FORCE EVALUATION MODEL

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The Combat Sample Generator Model (COSAGE) is being replaced by the Vector-In-Command model (VIC) as the feeder model to the Force Evaluation Model (FORCEM) at the US Army Concepts Analysis Agency (CAA). This thesis presents and analyzes the two general methodologies in use today for estimating the attrition coefficients in a high resolution model : the self contained model and parameter fit model. It offers the analyst a framework for taking the output reports generated by the VIC model and incorporating these into FORCEM, much as COSAGE's outputs are now currently inputted into FORCEM via the Attrition Calibration Model (ATCAL). This thesis focuses on the ability of VIC to enhance FORCEM. This includes VIC being able to compute non-conventional warfare results and carry these results through ATCAL into FORCEM. VIC also enhances the capability of FORCEM via ATCAL to predict battle results and is able to extract information about the dynamics of the battle in smaller than the present 12 hour time steps.

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I. INTRODUCTION

A. BACKGROUND

A key function of Army combat simulations is the calculation of losses of equipment and personnel by the engaged forces. The simulation is accomplished through a detailed treatment of all shooters and potential targets. At the US Army Concept Analysis Agency (CAA), the Combat Sample Generator (COSAGE) model is utilized for high resolution treatment of combat engagements of divisions and lower echelons.

At theater-level a detailed treatment becomes difficult, therefore attrition equations are used to relate numbers of shooters and targets to losses. At CAA, the current theater-level wargame is the Force Evaluation Model (FORCEM) which is a computerized, low resolution simulation of theater campaign combat and support operations. The model is a deterministic, time-stepped (minimum 12 hour step) representation which is designed to simulate up to 180 days of conflict in an uninterrupted computer run. Units (divisions, artillery/missile battalions, logistics installations, etc.) are represented as model entities with locations and assets (equipment, vehicles, supplies, personnel, etc.). Terrain features are represented on a grid square basis (average 10 kilometer square) with descriptors of surface roughness, vegetation, rivers, roads, bridges, and cities.

At each 12 hour step in the model, various events and routines are called that assess the results for the preceding 12 hours and determine the course of action for the next 12 hours. During these periods, the fire planning and the command and control occur. During the fire planning, targets and weapons are matched and a plan is produced that depicts how an attack would occur. The fire plans that are selected are stored in a set. This set contains entities which represent a notional weapon attacking one target. Each of these entities is a feasible mission. A notional weapon is entirely defined by the user and may represent any number of individual weapons desired. The weapons must be predefined and the effects against the various targets computed prior to initiating the FORCEM run. [Ref. 1]

This thesis will examine how FORCEM estimates material damage and rounds expended in a combat engagement using the Attrition Calibration (ATCAL) model.

ATCAL uses auxiliary equations to feed the main attrition equations, modifying their parameters and thereby accounting for considerable battlefield detail. This added flexibility permits better portrayal of the results of force variations. The method uses high-resolution results directly (without intermediate statistical procedures) and provides useful side information in addition to the loss-by-cause table (commonly referred to as a killer-victim scoreboard). The ATCAL model is a low resolution combat model that consists of two components. The first component (ATCAL Phase I) is a stand alone version where parameter values are generated that represent the particular engagement. These parameter values are then stored by specified engagement factors such as size and type forces in a file for future use. Then ATCAL Phase II, the second component of the ATCAL model, uses the most appropriate ATCAL Phase I parameter values to estimate the material damaged and rounds expended in any Division engagement that FORCEM requests.

ATCAL is needed because it is a fast running representation of a high resolution simulation. In a theater campaign, there may be as many as 10,000 division engagements in a 30 day time period. A high resolution simulation of one engagement takes several hours in COSAGE, but only a few seconds using ATCAL. [Ref. 2]

Currently COSAGE is the high resolution model that provides the input values to FORCEM via ATCAL. By 1988, COSAGE will be replaced by a new model, VECTOR-IN-COMMAND (VIC). To better visualize the interaction between the combat models discussed above, a flowchart is provided in Figure 1.1.

B. THE PROBLEM

VIC is a significantly different model than COSAGE, possessing additional capabilities that will enable FORCEM to become a more powerful model. One apparent weakness in the FORCEM model is the constraint of a minimum of a 12 hour time step. This large time step makes FORCEM unable to take the end of battle results and break these down by use of an audit trail to determine the dynamics of a combat engagement. The present FORCEM model does not lend itself to detailed analysis. The VIC model may be able to provide this additional capability to FORCEM without any loss to FORCEM's present capabilities. Being able to determine the dynamics of a battle would enable military planners to better understand the results of a theater level engagement and to examine any result that may not be consistent or logical.

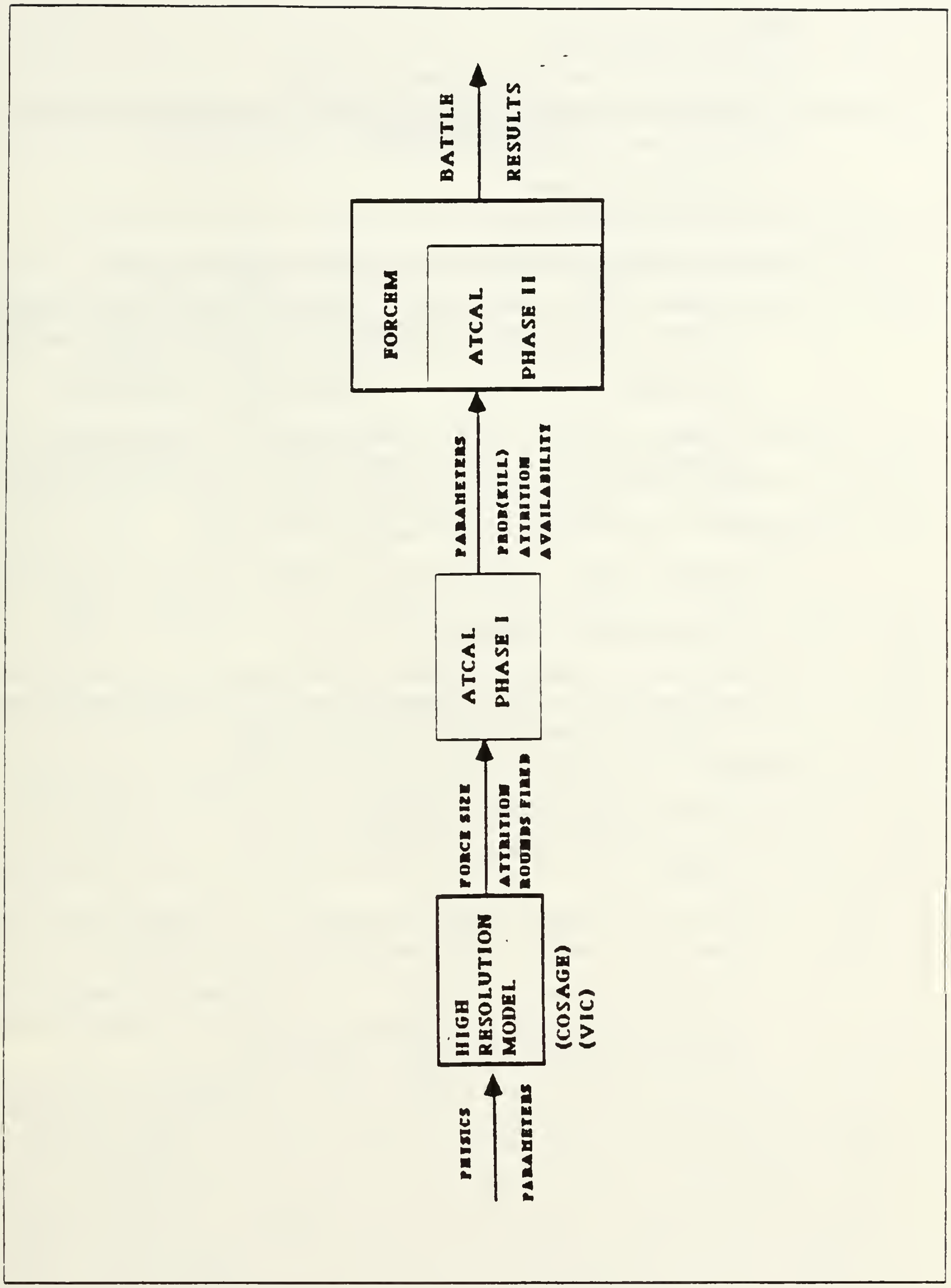

Figure 1.1 Interactions between combat models.

C. THESIS OBJECTIVES

The objectives of this thesis are described below.

1. Examine the two general methodologies for providing input to a higher level, low resolution model from a high resolution feeder model.
   a. Parameter fit model
   b. Self-contained model
2. Examine parameter generation for input to a higher level model.
   a. Examine Clark's methodology of utilizing a high resolution model output as input into the Combat Analysis Model (COMAN) Maximum Likelihood Estimation (MLE) which will generate output parameters for the higher level model.
   b. Examine in detail ATCAL's methodology of utilizing a high resolution model's output such as COSAGE or VIC as input into ATCAL Phase I which will generate output parameters for the higher level model.
3. Examine routines which compute-end-of battle results.
   a. Examine Clark's methodology for utilizing the output parameters from the COMAN MLE model as input into the COMAN model which will compute end-of-battle results.
   b. Examine in detail ATCAL's methodology for utilizing the output parameters from ATCAL Phase I as input into ATCAL Phase II which will compute equipment damaged and rounds fired.
4. Examine VIC's capability as a feeder model to FORCEM via ATCAL.
   a. Compare COSAGE and VIC output.
   b. Determine how to best utilize the additional information from the VIC model.
   c. Examine FORCEM's added capability if it can draw from an expanded library of parameter values generated by ATCAL Phase I.
   d. Examine the concept of analyzing the dynamics of the battle rather than just the final results by breaking the battle into phases to capture the different tactics within an overall engagement.

Chapter II discusses the two methodologies for providing input to a higher level model: the parameter fit model and self-contained model. The chapter provides details on the self-contained methodology and an overview of the VIC model. Chapter III explains the parameter fit methodology with emphasis on the ATCAL and COMAN models. Chapter IV focuses on VIC's capability as a feeder model to FORCEM and examines VIC's additional capabilities and how they could be utilized in the ATCAL model to enhance FORCEM. Chapter V summarizes salient points observed and the areas for further (research) study.

II. TWO METHODOLOGIES FOR PROVIDING INPUT TO A HIGHER LEVEL MODEL

Currently there are two basic approaches for a high resolution feeder model to be utilized by a low resolution higher level model. These methods are a *parameter fit model* and a *self-contained model.* COMAN and ATCAL are parameter fit models whereas COSAGE and VIC are self-contained models.

A. PARAMETER FIT MODEL

A parameter fit model approach uses the output of a high resolution model, usually in the form of a killer-victim scoreboard, and through parameter generation provides inputs, usually in the form of specific parameters, to a higher level combat model.

The high resolution model such as COSAGE starts with the basic input data of probabilities of kill for each weapon system type. Here all blue and red weapon systems can be represented with associated synergism between systems, and a killer-victim scoreboard is produced as output from the high resolution model. The killer-victim scoreboard is a representation of the outcome of a specific engagement in terms of systems killed. This output is then used as input into the parameter fit model such as ATCAL Phase I. Once the parameters are determined from ATCAL Phase I, these parameters are fed into the higher level model such as FORCEM via a subroutine that uses these parameters to determine engagement results, such as ATCAL Phase II. Through this process, the effects of systems in the lower level model are represented in the higher level model.

In order for a system to be represented in a higher level model, it must be present in a lower level model. When a higher level model is required to simulate an engagement, there are two choices; it can represent each engagement by calling the lower level model for results or it can call a subroutine that approximates the results through parameters. For the latter approach, a library of engagements with the parameters of battle is required. At CAA, this library of engagements is stored as a result of ATCAL Phase I in 12 hour phases. The subroutine finds the "closest" blue-red force battle combination to the desired engagement and uses these parameters in ATCAL Phase II to determine the battle results. The advantage of using the

approximation is the savings in computer time and money. For example, a typical theater level engagement over a 30 day span could involve as many as 10,000 division level battles, using the parameter fit model these would take only minutes to compute but could take days if run at high resolution in COSAGE. The parameter fit model is explained in detail in Chapter III.

B. SELF-CONTAINED MODEL

The second approach is to use a self-contained model such as VIC. A self-contained model has the capability to determine attrition for any size force. This is possible because a self-contained model such as VIC uses differential rate functions which do not depend on the size of the force. Therefore, a self-contained model can provide whatever level of output is desired depending on the size and scale of the input values. However, this approach has a major drawback in that synergistic effects of multiple weapons used in a combined arms sense are difficult to represent. This model uses individual probabilities of kill, number of rounds fired, and initial numbers of combat vehicles to determine battle results.

The self-contained model starts with the individual weapon systems characteristics of probability of kill. These characteristics are then used in differential rate functions. There is generally a different differential rate function for each part of a combat engagement, such as direct fire, area fire, helicopters and air. This generates a killer-victim scoreboard and battle results. These results can be used by FORCEM directly or provided to ATCAL Phase I to generate parameters for ATCAL Phase II for input into FORCEM. This thesis will focus on utilizing the output from a self-contained model such as VIC as input into a parameter fit model such as ATCAL. The ability to feed VIC's output directly into FORCEM is mentioned as an area of future study in Chapter IV, Section D.

The Bonder/Farrell Analytical model, utilized in the development of VIC, can predict the effectiveness of combat units. In this approach, the physical combat is decomposed into its basic elements. Mathematical descriptions of these elements are developed, and these elements are integrated in an assumed overall mathematical structure. Solutions are obtained by consistent mathematical operations giving rise to relationships between independent and dependent variables of combat effectiveness.

Ideally, there exists some functional relationship between the results of the battle and the initial numbers of forces, types and capabilities of the weapons systems, the doctrine of employment, and the environment. Since this can not be done directly, one

approximates a small period of time during the battle and extrapolates the results. Different groups on the battlefield are identified by their ability to attrit weapons systems of an opposing group. For purposes of this discussion, the subscripts i and j relate to the blue and red forces, respectively. Thus the overall analytic structure of the combat activity is based on the assumptions that

(1) The rate of loss of units in the jth group due to the ith group is proportional to the number of units in the ith group with a proportionality factor called the *attrition coefficient*,

(2) The rate of loss of units in the jth group in total is the sum of the rates of losses due to different ith groups.

Mathematically, these assumptions take the form of the following coupled sets of differential equations.

$$dN_j/dt = -\Sigma_i (A_{ij} \times M_i) \quad \text{for } j = 1,2 ..,J \qquad \text{(eqn 2.1)}$$

$$dM_i/dt = -\Sigma_j (B_{ji} \times N_j) \quad \text{for } i = 1,2,..,I \qquad \text{(eqn 2.2)}$$

where

The *blue attrition coefficient* (A_{ij}) equals the number of systems attrited in the ith blue group by the jth red group.

The *red attrition coefficient* (B_{ji}) equals the the number of systems attrited in the jth red group by the ith blue group.

N_j = size of the red force of system type j.

M_i = size of the blue force of system type i.

It is noted that this formulation is deterministic, which treats the numbers of surviving forces as continuous variables, while clearly the actual battle activity is a random phenomenon and the surviving forces are integer valued variables. The attrition coefficients are complex functions of the weapon capabilities, target characteristics, distribution of the targets, etc. The model attempts to reflect these complexities by partitioning the total attrition process into four distinct areas:

(1) The effectiveness of weapons systems while firing on live targets, often called the *attrition rate*.

(2) The allocation procedure of assigning weapons to targets, called the *allocation factor.*

(3) The inefficiency of fire when other than live targets are engaged, called the *intelligence factor.*

(4) The effect of terrain on limiting the firing activity and on mobility of the systems.

The attrition rate is assumed to be dependent on a multitude of physical parameters of a weapon system which describe its capabilities in such areas as acquisition, firing accuracy, delivery rate, and warhead lethality. In this formulation we consider the range variation of the attrition rate explicitly and somewhat independently of the chance variation at each range to the target. [Ref. 3]

The Bonder/Farrell differential rate model uses the assumption that an underlying Lanchester process is occuring and determines kill rate, A_{ij}, by eqn 2.3. For the remainder of this discussion, A_{ij} is defined as the number of kills of system type i per time per firer of type j. $E(T_{ij})$ = mean time between kills.

$$A_{ij} = 1 / E(T_{ij}). \qquad \text{(eqn 2.3)}$$

Two models used to determine kill rates are discussed below. These will be presented for the homogeneous case, but the models are readily applicable to the heterogeneous representation of each unit type within the force as given in eqn 2.3.

The first formulation of an analytical model uses the following assumptions and notation:

(1) Single independent repeated shot model.

(2) Firer shoots at a fixed rate until target is killed.

(3) Each shot is totally independent.

(4) t_s = time to fire each shot.

(5) p_{kill} = probability of a kill.

(6) $p_{k|h}$ = probability of a kill given a hit.

(7) $p_{h|h}$ = probability of a hit given a hit.

(8) $p_{h|m}$ = probability of a hit given a miss.

(9) $p_{h|s}$ = probability of a hit given a shot.

(10) p_1 = probability of a first round hit.

(11) $p_s = p_{kill} / \text{shot} = p_{k|h} \times p_{h|s}$

(12) $T = t_s \times n$ where n is the number of shots required to kill target. T is a random variable which is acquisition time plus kill time.

(13) $v_s = 1 / t_s$

Now $E(T) = t_s \times E_n$ where $E_n = 1 / p_s$ and

$$E(T) = 1 / (v_s \times p_s). \qquad \text{(eqn 2.4)}$$

A second formulation is that of a Markov fire attrition rate followed by a renewal process to predict the attrition rate. Suppose that there is a model that consists of three states where

- state 1 = new engagement state
- state 2 = hit state
- state 3 = miss state

If it is assumed that the shots are not independent but are *Markovian*, the result of each shot depends only on the previous shot. Consider a renewal process where each time a target is killed the process starts over. In order to determine the average time to a kill or renewal, Barlow's Theorem is required (eqn 2.5). Let T be a random variable denoting the time between entries into state 1.

Barlow's Theorem states that the mean recurrence time, TAU_i, for any state i, is given by

$$TAU_i = (\Sigma_j (II_j \times M_j)) / II_i \qquad \text{(eqn 2.5)}$$

and

$$E(T) = TAU_1 = (\Sigma_j (II_j \times M_j)) / II_1 \qquad \text{(eqn 2.6)}$$

where

M_i is the unconditional mean wait time in state i,

W_{ij} is the mean wait time in state i, given transition from i to j.

II_j are the Markov chain steady state frequencies.

These parameters are related as follows:

$M_i = \Sigma_j (P_{ij} \times W_{ij})$, where $\Sigma_j P_{ij} = 1$.

$II_j = \Sigma_i (II_i \times P_{ij})$

$\Sigma_i II_i = 1$.

Therefore one solves for the kill rate by solving for the inverse of the expected time to a kill. [Ref. 4] In this particular example involving three states,

$$E(T) = M_1 + (a_2 \times M_2) + (a_3 \times M_3) \qquad \text{(eqn 2.7)}$$

where

$$a_2 = \Pi_2 / \Pi_1 = (1-p_{k|h}) / p_{k|h}$$
$$a_3 = \Pi_3 / \Pi_1 = (1 / p_{h|m}) \times (((1-p_{h|h}) / p_{k|h}) + p_{h|h} - p_1)$$

C. SUMMARY

FORCEM is the current theater level combat model used at CAA. FORCEM is a deterministic, low resolution model that is currently using a stochastic high resolution model, COSAGE, as its feeder model. Before FORCEM can use the output results from COSAGE, the output is run through the ATCAL model which produces parameters which are then converted to attrition results for use in the FORCEM model. COSAGE is going to be replaced by another self-contained model, VIC, which is a deterministic model using difference equations to obtain attrition results. Chapter III describes how the parameter fit model works with the Combat Analysis Model Maximum Likelihood Estimater (COMAN MLE) and ATCAL Phase I. The primary emphasis will be on ATCAL Phase I, because that is the model CAA uses to generate the parameters needed for FORCEM via ATCAL Phase II.

III. PARAMETER FIT MODEL

A. PARAMETER GENERATION FOR INPUT TO A HIGHER LEVEL MODEL

1. INTRODUCTION

Parameter generation for input to a higher level model involves taking the output from a lower level model and generating the necessary parameters for use in a higher level model. These parameters are then used to predict attrition results by interpolation or extrapolation. Two models, Combat Analysis Maximum Likelihood Estimator model (COMAN MLE) and ATCAL Phase I, are used as examples of the parameter fit methodology. The COMAN model will provide insight into how the parameter fit model operates. The ATCAL model is very similar to the COMAN model and will be examined in detail because it is the current model that takes COSAGE output and converts it to useable data through parameter generation and prediction. This chapter indicates how the necessary parameters are generated through COMAN MLE and ATCAL Phase I and thus provides insight as to the best methodology for implementation of VIC as the feeder model for FORCEM. The last part of this chapter shows how ATCAL Phase II uses the parameters to compute attrition and end of battle results for any specific engagement.

2. COMAN MLE MODEL

COMAN is an efficient attrition model which characterizes the attrition results of a discrete event simulation by developing maximum likelihood estimates (MLE) of kill rates. COMAN incorporates a fixed target prioritization scheme in its acquisition process, imposing three important restrictions:

a. Firers engage only the highest priority targets that they have acquired.

b. The relative priority of targets is the same for all firers.

c. It is only good for repetitive processes, not infrequent events.

COMAN consists of mathematical expressions which predict attrition as a function of the initial force mixes of two opposing forces. Weapon kill rates and target acquisition probabilities are parameters in the COMAN model. These parameter values are estimated from data generated by the combat simulation. Thus, COMAN predicts attrition expected for various force mixes based upon the tactical doctrine, weapon designs, and battlefield environment represented by the combat simulation. The model

facilitates weapon-mix studies and permits an efficient use of a high resolution model. The model is employed by first running the simulation to determine combat outcomes such as killer-victim scoreboards and then uses COMAN to extrapolate or interpolate these simulation results for weapon mixes not explicitly evaluated by the simulation. A preferred weapon mix can be identified in this manner, and the simulation can be operated again to check the results of the COMAN model. By alternately using the simulation and COMAN, the preferred weapon mix can be found. Figure 3.1 depicts the proposed method of using the COMAN model in the analysis of weapon mixes.

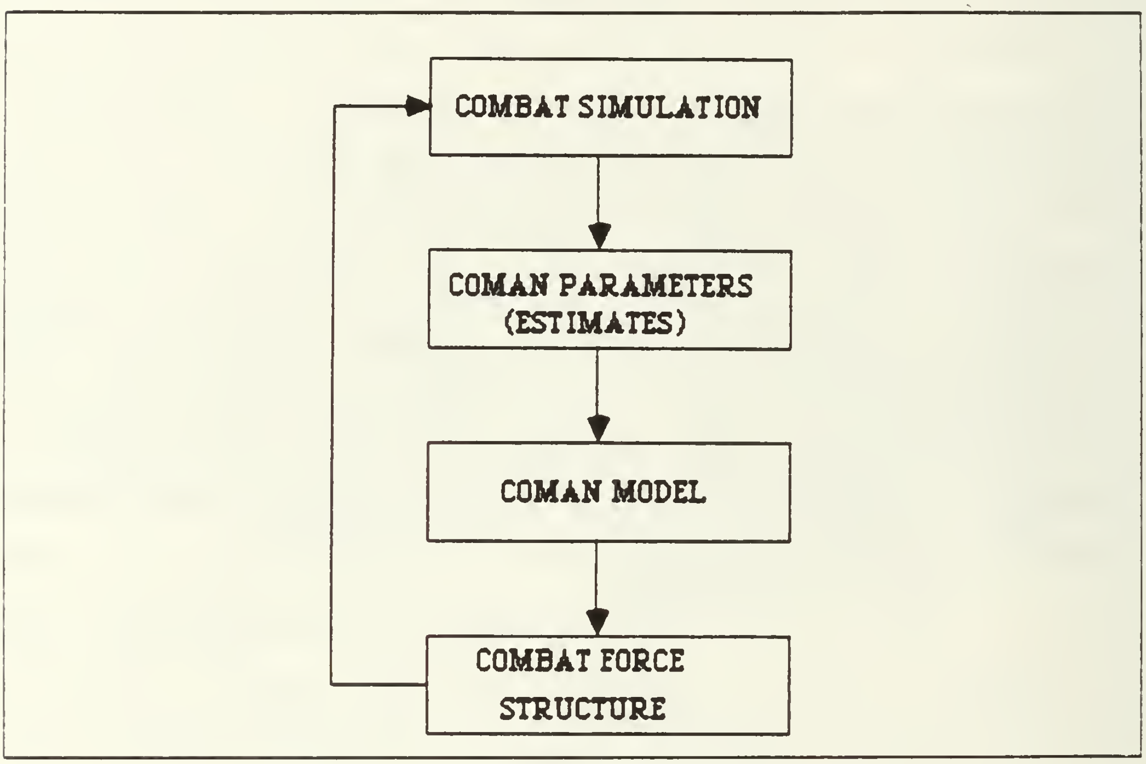

Figure 3.1 Method of Using COMAN Model.

COMAN has the ability to interpret relationships presented in the simulation by analysis of the parameters. The fundamental concept used in constructing COMAN is the kill rates for specific firer-target type combinations. These kill rates are estimated from the simulation data, and provide insight as to the relative effectiveness of various weapon types without resorting to numerous simulation runs. COMAN is also suitable for describing the attrition resulting from battalion-sized engagements in a large-unit model.

TABLE 1

VARIABLE AND PARAMETER NAMES FOR COMAN

A = estimator for kill rate of blue firers against red targets.
B = estimator for kill rate of red firers against blue targets.
a = number of blue casualties / (red firer) (time)
b = number of red casualties / (blue firer) (time)
x = blue force size continuous random variable
y = red force size continuous random variable
T = total number of casualties.
m = size of blue force at time t, a realization of the random variable $M(t)$.
n = size of red force at time t, a realization of the random variable $N(t)$.
m_k = size of blue force after k^{th} casualty.
n_k = size of red force after k^{th} casualty.

C_k^X = 1 if k^{th} casualty to blue, otherwise = 0.

C_k^Y = 1 if k^{th} casualty to red, otherwise = 0.

$C_T^X = \Sigma_k C_k^X$ = total number of X (blue) casualties.

$C_T^Y = \Sigma_k C_k^Y$ = total number of Y (red) casualties.

S_x = random variable of time to the next blue casualty.
S_y = random variable of time to the next red casualty.
f = density function
EXP = exponential function
t_k = time of occurrence of k^{th} casualty.
$t_k - t_{k-1}$ = simulation recorded time for the k^{th} casualty.

The COMAN model is a fitted parameter model which takes a time series of casualties and computes the MLE of time between casualties. The ability of the COMAN model to provide insight into the interactions being represented in the combat simulation is based on the estimation of attrition rates and the probabilities of targets being acquired from simulation data. [Ref. 5]

The values of the COMAN model parameters are represented as step functions which are constant within each time interval. The parameter values in each interval are regarded as being independent in the interval. Thus, the estimation of parameter values in a time interval is only a function of data in that interval and is not related to results in other time intervals. Since the values of the parameters for a time interval are independent of the values of other time intervals, the estimators can be

defined by analyzing a sample observed during a single time interval from each battle simulated. Thus, the sample consists of a number of observations during the interval taken from a number of independent replications of the combat simulation. The actual model is applied for the heterogeneous case in which each weapon system is represented. The derivation is presented for the homogeneous case to simplify notation. The variables and parameters for the COMAN model are given in Table 1.

The objective is to estimate the unknown parameters A and B, which are the MLE for a and b, respectively. Because of the memoryless property of the Markov process, we formulate the likelihood functions as the simple product of the likelihoods for each of the independent kill time events. The contribution of the k^{th} casualty to the likelihood function equals the probability that it used the recorded amount of time from the simulation. An example of this concept was demonstrated by Clark with the COMAN model. A 45 minute battalion level battle was simulated. It became apparent that the battle occurred in three phases. These phases were considered as the long, medium, and short range battles because weapon lethalities are a strong function of range. The COMAN model used this concept to compute different MLEs for each interval. In this way the k^{th} casualty occurred very close to where the maximum likelihood function estimated the occurrence. Otherwise, with no partitions of the battle, these groupings of casualties at different intervals could not be adequately estimated with one single MLE.

For this discussion the MLEs for the Markov-chain analog of the deterministic Lanchester Square Law Combat model are computed. This model is mathematically represented by the following set of equations (eqns 3.1, 3.2).

$$dx/dt = -a\,y \qquad \text{(eqn 3.1)}$$

$$dy/dt = -b\,x \qquad \text{(eqn 3.2)}$$

The transition probabilities for the continuous time Markov-chain attrition are given by equations 3.3 and 3.4.

$$P(\text{ X casualty in } \Delta t) = a\,n\,\Delta t \qquad \text{(eqn 3.3)}$$

$$P(\text{Y casualty in } \Delta t) = b\, m\, \Delta t \qquad \text{(eqn 3.4)}$$

There are three steps required to determine the maximum likelihood estimators, A and B.

a. The first step is to determine the probability density function (pdf) for the time to an X casualty (also for the time to a Y casualty). In this case the pdfs are shown in equations 3.5 and 3.6.

$$f_{Sx}(s) = a\, n\, \mathrm{EXP}(-(an + bm)\, s) \qquad \text{(eqn 3.5)}$$

and

$$f_{Sy}(s) = b\, m\, \mathrm{EXP}(-(an + bm)\, s) \qquad \text{(eqn 3.6)}$$

b. The second step is to construct the likelihood function, L(a.b). It is the density function for the observed sequence of events. Suppose a casualty has just occurred at t_k. This makes a contribution to the likelihood function, l_k, and L(a,b) is given by eqn 3.7.

$$L(a,b) = \Pi_k\, l_k \qquad \text{(eqn 3.7)}$$

where

$$l_k = (an_{k-1})^{C_k^X} (bm_{k-1})^{C_k^Y} (\mathrm{EXP}(-(a\, n_{k-1} + b\, m_{k-1})(t_k - t_{k-1})))$$

c. In the final step we determine the values for the parameters a and b that maximize the likelihood function (A and B, respectively). We first compute the natural logarithm of the likelihood function where ln L(a,b) = Z.

$$Z = \Sigma_k C_k^X \ln(an_{k-1}) + \Sigma_k C_k^Y \ln(bm_{k-1}) - \Sigma_k (an_{k-1} + bm_{k-1})(TT) \qquad \text{(eqn 3.8)}$$

where $TT = t_k - t_{k-1}$

Then we take the derivative and set it equal to zero to obtain the maximum likelihood estimates (A and B) given by equations 3.9 and 3.10.

$$A = C_T^X / (\Sigma_k\, n_{k-1}\, (t_k - t_{k-1})) \qquad \text{(eqn 3.9)}$$

$$B = C_T^Y / (\Sigma_k m_{k-1} (t_k - t_{k-1})) \quad \text{(eqn 3.10)}$$

Clark's stochastic methodology as shown via the COMAN model uses the results of a stochastic high resolution model to determine the COMAN parameter values for weapon kill rates and target acquisition which are used in determining the attrition rates. In the next section, the ATCAL model uses a methodology similar to Clark's stochastic methodology in incorporating COSAGE's output into FORCEM via ATCAL. [Ref. 6]

3. ATCAL PHASE I

The ATCAL model uses auxiliary equations to feed the main attrition equations, modifying their parameters and thereby accounting for battlefield detail. ATCAL Phase I estimates the parameters for the two attrition equations, point fire and area fire (see Table 2 for definition of variables and indices). As the ATCAL model sequentially processes the weapon types on each shooting vehicle, it encounters an indicator which tells it whether the weapon is to be processed with point fire or area fire logic. For point fire, the attrition equation must take into account the following two parameters:

(a) *Availability* (AV_{ijk})

(b) *Probability of kill* (P_{ijk})

For area fire, the attrition equation must take into account the following three parameters:

(a) *Response Factor* ($RSPNS_i$), the amount of firing that is to be done.

(b) *Bias Factor* ($BIAS_{ij}$), the apportionment of the firing among the different round types.

(c) *Lethality Factor* (L_{ijk}), the effects of the firing on the target arrays.

In ATCAL Phase II, these stored parameters from ATCAL Phase I are used to determine the losses (X_{ijk}) in the new mix of forces.

a. ATCAL POINT FIRE Phase I

For point fire, several parameters are used as input to the ATCAL Phase II attrition equation given in eqn 3.11.

$$(X_k)_{ij} = VA_i \, RATE_{ij} \, P_{ijk} \, (1-(1-AV_{ijk})^{VA_i}) \quad \text{(eqn 3.11)}$$

TABLE 2

SUBSCRIPTS AND VARIABLE NAMES FOR ATCAL

• i =	firer vehicle type
• j =	weapon round type
• k =	target vehicle type
• N_k =	The initial number of combat vehicles of type k at the beginning of the battle.
• $(X_k)_{ij}$ =	The killer-victim scoreboard is the total number of casualties of type k during the entire battle which were caused by all firers of type (i,j).
• RD_{ijk} =	the number of type j rounds fired at type k targets by type i firers.
• A_{ijk} =	rate at which type i firers with type j rounds kill target type k.
• P_{ijk} =	single shot probability of kill.
• AV_{ijk} =	the fraction of time a single particular target type k can be fired upon by a firer type i with round type j.
• $RATE_{ij}$ =	the maximum amount of fire a weapon can deliver over the time of the engagement. It is a non-linear parameter that is estimated using simulation with varied numbers of targets. This is a complicated procedure and is done off-line, not part of ATCAL proper.
• $RANGE_{ij}$ =	the average engagement range for weapons of type (i,j).
• WIDTH =	the width of the combat front for the engagement.
• E_{ij} =	the expenditure of rounds of type j from systems of type i.
• VA_i =	average number of type i vehicles available . The term is used to denote the killable entity on the battlefield.
• VI_i =	vehicle importance represents the lethality of the enemy's equipment. It can be thought of as the potential kill rate the shooter saves on his side by eliminating his opponents. VI_i is defined as the importance of all shooters of type i at the start of the battle. Vehicle importances are derived using the sort of circular reasoning used in the eigenvalue scoring method.

In phase I, the parameters AV_{ijk} *and* P_{ijk} are determined as described below. In order to solve for these parameters in ATCAL Phase I, ATCAL requires certain inputs from a high resolution model such as VIC or COSAGE. These inputs include initial size of forces (N_k), attrition during the period (X_{ijk}), and the number of rounds expended by each force by weapon system (RD_{ijk}).

(1) Compute total casualties to vehicles of type k by summing the killer-victim scoreboard values.

$X_k = \Sigma_{i,j} (X_k)ij$

(2) Compute the average number of vehicles (VA_k) for all vehicle types from the input loss data. Vehicles and their average number are used throughout ATCAL. The term is used to denote the killable entity on the battlefield. Each vehicle can be both shooter and target. The average numbers of vehicles of each type in the engagement are used in the attrition equations to produce a dynamic model which responds appropriately to changes in engagement length.

$VA_k = (-X_k / \ln (1-(X_k / N_k)))$

(3) Compute P_{ijk} as a ratio of two inputs: loss matrix element $((X_k)_{ij}$ and firing matrix element (RD_{ijk}).

$$P_{ijk} = (X_k)_{ij} / RD_{ijk} \qquad \text{(eqn 3.12)}$$

(4) Compute vehicle importances (VI_i) using the starting numbers of vehicles, the loss matrix and the importance values, VI_k, of the enemy units. Vehicle importance represents the lethality of the enemy's equipment and ATCAL will try to destroy those systems first. Importances of weapons are a vital assessment in ATCAL and come from a nonlinear operation on the killer-victim scoreboard. Vehicle importance is a nonlinear operation on the kill matrix. Vehicle importance can be thought of as the potential kill rate the shooter *saves* on his own side by eliminating his opponents. Vehicle importance is computed in both phases of ATCAL.

$VI_i = (\Sigma_k((X_k)_i^3 VI_k / (X_k \times (N_k)^2)))^{(1/3)}$

(5) Compute the target priorities (Q_{ijk}) for each shooter type, using the vehicle importances and the probability of kill values. Target priorities allow the model to compute allocations of fire to targets. Target priority is computed as the product of kills per round and target importance.

$Q_{ijk} = P_{ijk} \times VI_k$

(6) Sort the targets by priority for each shooter type.

(7) Again for each shooter type, compute the availability parameter, AV_{ijk}, for each target, in priority order, from the relationship.

$$AV_{ijk} = 1-(1-(RD_{ijk} / (VA_i \times RATE_{ij})))^{(1/VA_k)} \qquad \text{(eqn 3.13)}$$

where

$$RATE_{ij} = (2 \times \Sigma_k RD_{ijk}) / N_i$$

(8) Finally the AV_{ijk} parameter is stored in frontage independent form by dividing each AV_{ijk} by the factor (1 - EXP($-RANGE_{ij}$ / WIDTH)). The average range of engagement for each weapon type is taken from the high resolution simulation and the width of the front is also taken from that simulation. This results in a scaling of availability to account for the width of the front in ATCAL Phase II.

These equations are used in the computations in the APL program (Appendix D) to determine the attrition in a few specific scenarios which will be discussed in Chapter IV.

b. ATCAL AREA FIRE Phase I

For area fire, the attrition equations are quite different from point fire as are all the parameters. The area fire parameters are *response* ($RSPNS_i$), *bias* ($BIAS_{ij}$), and *lethality* (L_{ijk}).

These parameters are then utilized in the area fire attrition equation 3.14 in Phase II of ATCAL.

$$X_{ijk} = E_{ij} \times P_{ijk} \times FRAC_{ijk} \qquad \text{(eqn 3.14)}$$

The steps to compute the parameters for phase I area fire are as follows. [Ref. 7]

(1) The average numbers and importances have already been computed and are known quantities from the ATCAL point fire Phase I routine.

(2) Compute the kills per round quantity from equation 3.15.

$$P_{ijk} = (X)_{ijk} / (RD_{ij} \times FRAC_{ijk}) \qquad \text{(eqn 3.15)}$$

where

$FRAC_{ijk}$ is a factor that depends on target priority. $FRAC_{ijk}$ is the fraction of rounds fired by firer type i of round type j which are capable of killing systems of type k. $FRAC_{ijk}$ is initially set at 1.0 since it depends upon target priorities which are not known at the beginning of the engagement.

(3) Compute target priorities (Q_{ijk}) by equation 3.16.

$$Q_{ijk} = P_{ijk} \times VI_k \qquad \text{(eqn 3.16)}$$

(4) Compute normalized target priorities (QN_{ijk}) from equation 3.17.

$$QN_{ijk} = Q_{ijk} / \Sigma_k Q_{ijk} \qquad \text{(eqn 3.17)}$$

(5) Compute $FRAC_{ijk}$ from equation 3.18.

$$FRAC_{ijk} = VA_k / (VA_k + \Sigma_k QN_{ijk} \times VA_k) \qquad \text{(eqn 3.18)}$$

(6) Update the P_{ijk} in step 2 by using the FRAC quantity just computed.

(7) Iterate over steps 2 through 7 until P_{ijk} converges to a fixed value. At this point it is possible to compute the calibration parameters (L_{ijk}, $BIAS_{ij}$, and $RSPNS_i$) in steps 8 through 11.

(8) Compute the *lethality* parameter (L_{ijk}) from equation 3.19.

$$L_{ijk} = (N_k / VA_k) \times P_{ijk} \qquad \text{(eqn 3.19)}$$

(9) Compute the mission priority from equation 3.20.

$$MUNPR_{ij} = \Sigma_k P_{ijk} \times VI_k \times VA_k \qquad \text{(eqn 3.20)}$$

(10) Compute *bias* parameter using equation 3.21.

$$BIAS_{ij} = JCOUNT_i \, ZZ_{ij} / \Sigma_j ZZ_{ij} \, . \qquad \text{(eqn 3.21)}$$

where

$JCOUNT_i$ = number of area fire round types on each vehicle of type i.

ZZ_{ij} is ratio of rounds fired (RD_{ij}) and munition priority ($MUNPR_{ij}$).

$ZZ_{ij} = RD_{ij} / MUNPR_{ij}$

(11) Compute *response* parameter ($RSPNS_i$) from equation 3.22.

$$RSPNS_i = \Sigma_j RD_{ij} / \Sigma_j MUNPR_{ij} \qquad \text{(eqn 3.22)}$$

B. UTILIZING PARAMETERS FOR ESTIMATION : ATCAL PHASE II

The previous section discussed parameter generation for input to a higher level model. In this section, these parameters are then used to generate combat losses (X_k). ATCAL Phase II is used within FORCEM to predict results when new force mixes are employed. In ATCAL there are different attrition equations for point and area fire and therefore two separate ATCAL PHASE II routines are utilized.

1. ATCAL POINT FIRE Phase II

ATCAL Phase II uses the closest set of parameter values generated by ATCAL point fire Phase I to predict the battle results of the new mix of forces. The following discussion lists the steps involved.

a. Set average number of vehicles (VA_k) and vehicle importances (VI_k) to their initial values. Bad starting points may force Phase II to iterate a few more times, but the final result does not depend upon starting points.

b. Scale the stored availability numbers according to the front width of the present engagement.

$$A_{ijk}(\text{scaled}) = AV_{ijk} / (1 - \exp(-RANGE_{ij} / WIDTH))$$

c. For each weapon in turn, compute its target priorities and apply the attrition equation (eqn 3.11) to each target in priority sequence. When all targets have been processed for a shooter, a check must be made to see if the ammunition stockpile was exceeded. The firing at each target type is found by dividing the kills per system by the stored kills-per-round figure. If the total rounds fired over all target types exceeds the ammunition constraint, firing is deleted from targets in reverse priority order until the constraint is met. The kills of those deleted targets are also subtracted from the previously determined matrix.

d. When all shooter types on a side have been processed, another adjustment is made to the attrition matrix to insure that losses do not exceed vehicles present.

e. The importances of all vehicles on the shooting side can be updated with another iteration each time a side is processed by the rest of the model.

f. Each time a full iteration is completed, a test for convergence is made. This consists of counting how many individual average number of vehicles values did not repeat their values of the previous iteration. When this count drops to near zero the run is over.

2. ATCAL AREA FIRE Phase II

In Phase II of area fire, the parameters generated by area fire ATCAL Phase I are used to predict the results of the battle in the following steps. [Ref. 7]

a. Compute the set of target priorities (Q_{ijk}).

b. Compute the munition priorities ($MUNPR_{ijk}$) and the demand for fire from equation 3.19. Then impose the biases on the munition priorities. The munition priorities are replaced by their biased equivalents during the rest of the loop.

c. Compute the number of rounds fired by all systems of type i.

d. Next, the allocation of round type j from system type i against system type k is made (E_{ijk}).

e. Compute $FRAC_{ijk}$ from equation 3.18.

f. The last step is to compute the kills of targets of type k by weapon system type i with round type j as shown below (eqn 3.11.).

$$X_{ijk} = E_{ij} \times P_{ijk} \times FRAC_{ijk}$$

C. SUMMARY

The ATCAL Phase I model uses the parameter fit methodology to generate the parameters for use in FORCEM via ATCAL Phase II. Then ATCAL Phase II uses these parameters to compute end of battle results. After examining the two methodologies for the two parameter fit models, COMAN and ATCAL, there is one major difference. The COMAN model breaks up the battle into time segments based on the casualty rate so it can get a MLE for each segment or phase. ATCAL, on the other hand, can only generate parameters in 12 hour segments since information provided by COSAGE, it's feeder model, comes in 12 hour steps. This topic will be covered in greater detail in Chapter IV along with an examination of VIC's capabilities as a feeder model to FORCEM.

IV. ANALYSIS OF VIC'S CAPABILITY TO ENHANCE FORCEM

As stated earlier, CAA plans to replace COSAGE with VIC as the feeder model to FORCEM by 1988. In this chapter example outputs, similar to those produced by VIC and COSAGE, will be compared to investigate whether VIC provides any additional information that would make FORCEM a more powerful model. The ability of FORCEM to draw from a larger inventory of ATCAL Phase I results will be examined. The last section will discuss areas of future study.

A. COMPARE COSAGE AND VIC OUTPUT

ATCAL is the current parameter fit model internal to FORCEM. ATCAL applies the corresponding engagement coefficients to the actual distribution of shooters and targets on each side to determine losses and expenditures. The minimum required inputs to ATCAL from a high resolution model are as follows.

- Initial number of combat vehicles.
- Killer-victim scoreboard.
- Number of shots fired for each firer at each target during each time period, k.
- Average engagement range.
- Combat width.

ATCAL then uses these outputs from the high resolution model to provide the following outputs that are utilized in FORCEM. ATCAL's primary output is total number of casualties to vehicles, but it also computes other reports as listed below.

- Allocation of fire among all shooters and target types.
- Ammunition expenditure.
- Relative importance of weapons.
- Force ratio.

1. COSAGE OUTPUT

COSAGE is the current feeder model to FORCEM providing the minimum required output for ATCAL in 12 hour time steps. Because of the stochastic nature of COSAGE, this 12 hour battle can not be divided into smaller time steps for analysis. This important point is discussed later in this chapter. The reports generated by COSAGE are as follows, with primary focus on equipment and ammunition.

(a) Summary Report

(b) Unit Array

(c) Wartime Replacement Factor Output

(d) Ammunition Expenditure Report

(e) Red Killer-Victim Report

(f) Blue Killer-Victim Report

(g) Artillery Ammunition Expenditure Report

(h) Unit Status Report

(i) Unit Equipment Quantity Report

(j) Attrition Data Report

(k) Stylized Expenditure Data Report

(l) Input Data Analysis Report

(m) Tactical Air Data Report

(n) Close Air Support Mission Report

COSAGE then catalogs a 12 hour time segment of a battle by posture (attack, defense intense, delay and static), type force (armor, mech, light infantry), number of replications, type terrain and battlefield width. Once the battle has been cataloged, it can be used in ATCAL Phase I to determine the output parameters of probabilities of kill (P_{ijk}), attrition rates (A_{ijk}) and availabilities (AV_{ijk}) for a specific 12 hour engagement.

2. VIC OUTPUT

VIC also provides the minimum output required for ATCAL but in any size time step. VIC generates many reports and these reports are divided into three groups.

(a) Reports printed every data interval.

(1) Killer-victim table by weapon.

(2) Killer-victim table by weapon category.

(3) Strength of ground/air units.

(4) Tables and plots for ground units, artillery units, command posts and air defense units.

(5) Ammunition round type by weapon system.

(6) Number of fire missions by range band.

(7) Number of weapon categories by air missions and aircraft type.

(8) Artillery munition usage table.

(9) Global air munition usage table.

(b) Reports printed at end of battle summary.

(1) Total number of fire missions by range band.

(2) Killer-victim scoreboard.

(3) Artillery munition usage summary.

(4) Global air munition usage summary.

(5) Forward Edge of the Battle Area summary plot.

(c) Reports printed at end of simulation.

(1) Blue/red losses per interval.

(2) Blue/red losses accumulated per interval.

(3) Loss exchange ratio per interval.

(4) Strength of ground units by the top three command levels.

(5) Force ratio.

(6) Surviving force ratio differential.

(7) Ammo round type verses weapon category.

(8) Mine strength.

(9) Weapon categories killed by unit.

(10) Number of weapon categories killed by air missions and aircraft type.

While VIC catalogs a battle in a similar manner as COSAGE, its main advantage is its added capability to catalog a battle in any size time step desired. Further, when one compares the output of VIC to the output of COSAGE, it is readily evident that VIC has the capability to provide more information to FORCEM. This raises the possibility that the FORCEM model could be enhanced by using VIC as the feeder model for ATCAL.

B. ANALYSIS OF VIC'S ENHANCEMENT POSSIBILITIES

Enhancements are possible because VIC can provide input data to ATCAL Phase I in any time increment. By dividing the battle into smaller time segments, the ATCAL Phase I results compute more precise parameter values that will depict the dynamics of the battle during a particular time interval. Also the possibility of building a larger inventory of ATCAL Phase I results will result in FORCEM being able to depict the dynamics of a battle. This is exactly what the COMAN model does in its parameter generation. Clark realized the importance of partitioning the battle into intervals, thereby reducing the variance associated with the attrition rate estimators. For small unit battles, the most effective partition was by range, because attrition rates for specific firer-target combinations tended to stabilize in the long, mid, and close range battles. In the following examples, various partitions of the 12 hour battle in VIC are contrasted to illustrate the benefits that can be realized.

To illustrate VIC's enhancement capabilities, an ATCAL Phase I computer program was written for three cases (Appendixes C, D, E). In the first case the input parameters of rounds fired and losses over time are distributed uniformly over each time step and the output parameters of probabilities of kill, availabilities and attrition rates for each time step are computed. In this case the parameter outputs from ATCAL Phase I show very small changes from the single 12 hour run when the battle is broken into smaller time steps. The second case involves fixing end game results for losses and rounds fired, but different scenarios are used to arrive at these same end game results. This case examines the limited capability of the current FORCEM model to depict the dynamics of the battle. It also illustrates how the COMAN methodology could be used to enhance the ATCAL model by breaking the battle into smaller time intervals to produce estimators with smaller variance. The third case modifies one of the test runs in Case 2 and shows how the added capability of short time steps could be utilized in FORCEM to depict *nuclear effects*, which at this time is not possible in FORCEM.

1. CASE 1

In this case, one 12 hour battle was examined to determine how ATCAL Phase I parameters differ based on the time interval used. The 12 hour battle was analyzed with a program (Appendix C) which employs the ATCAL Phase I routine. The 12 hour battle was broken into equal time segments with the inputs of losses and rounds fired for the total battle being uniformly distributed over the segments. For example, if there were 10 rounds fired in the entire battle by firer type i against target type k, then for 2 time steps there would be 5 rounds fired per time step.

The specific 12 hour battle involves a blue force of 50 M1 tanks and 100 M2 anti-tank weapons, and a red force of 50 T-72 tanks and 100 AT-5 anti-tank weapons. The T-72 tanks fired 84 rounds at the M1 tanks and 14 rounds at the M2 weapons. The AT-5 fired 100 rounds at the M1 tanks and 23 rounds at the M2 weapons. Additionally, during this 12 hour engagement 20 M1 tanks, 35 M2 anti-tank weapons, 15 T-72 tanks, and 20 AT-5 weapons were destroyed. Utilizing this input in the ATCAL program (Appendix C), the variables and parameters were computed. Only one out of the eight possible combinations of weapons systems will be discussed for this 2 by 2 case. The other combinations of red firers against blue targets are given in Appendix F. Throughout the remainder of the thesis, the specific variables and parameters of the T-72 firing at the M1 target are considered.

The battle was first simulated in one time step of 12 hours. The variables of the T-72 firer and M1 target for Case 1 are shown in Table 3. Note that the last column labeled BL in all tables reflects the number of M1 survivors from all red firing systems, not just the T-72. The 12 hour battle was then broken into equal length time steps with uniformly distributed inputs of rounds fired and losses over time. With these inputs into the ATCAL Phase I routine, the effects on the generated parameters and variables were examined. As shown in Table 3 the breakdown of the battle was as follows: two six hour time segments, three four hour time segments, and six two hour time segments. Since the input was uniformly distributed over equal length time steps, the parameters were close to being the same throughout the engagement. Specifically, probability of kill (P_{ijk}) was 0.18 throughout the battle since $P_{ijk} = X_{ijk} / RD_{ijk}$ and X_{ijk} and RD_{ijk} were uniformly proportioned over the segments. The attrition rate parameter (A_{ijk}) was 0.025 for the 12 hour battle and for the first time steps of the partitioned battles. As the 12 hour segment was broken into smaller time steps, the attrition rate increased. This result was also expected as $A_{ijk} = X_{ijk}/(N_k \times T)$ where T = length of time step. The value of N_k was getting smaller, therefore causing an increase in A_{ijk} The blue forces were being attritted at a uniform rate per hour per red system, but by fewer red systems in the later time steps.

TABLE 3

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M1 IN CASE 1

	INPUTS			OUTPUTS		
Time steps	X	RD	P	A	AV	BL
00 - 12	15.0	84	.18	.025	.018	30
00 - 06	7.5	42	.18	.025	.014	39.92
06 - 12	7.5	42	.18	.030	.018	29.84
00 - 04	5.0	28	.18	.025	.013	43.26
04 - 08	5.0	28	.18	.030	.015	36.53
08 - 12	5.0	28	.18	.032	.018	29.80
00 - 02	2.5	14	.18	.025	.012	46.65
02 - 04	2.5	14	.18	.025	.013	43.30
04 - 06	2.5	14	.18	.030	.014	39.95
06 - 08	2.5	14	.18	.030	.015	36.60
08 - 10	2.5	14	.18	.030	.017	33.26
10 - 12	2.5	14	.18	.030	.018	29.91

Another parameter to consider is the availability parameter, AV_{ijk}. Availability is a non-linear relationship between the distribution of the rounds fired by a force against the number of enemy forces fired upon. AV_{ijk} was given by equation 3.13 and defined as the fraction of time a single particular target of type k can be fired upon by firers of type i with round type j. AV_{ijk} is a function of initial force sizes, total rounds fired by a system, rounds fired against a particular type system, vehicle averages and $RATE_{ij}$. For example by analyzing equation 3.13, it becomes evident that by changing vehicle averages, availability will vary. If vehicle average for the target (VA_k) decreases then AV_{ijk} increases. Also as vehicle average for the firer (VA_i) decreases, AV_{ijk} increases.

In Case 1, the overall 12 hour battle availability parameter value is 0.018 when the T-72 engages an M1. This means that for any single M1 tank, that M1 can be fired upon by any T-72 tank 1.8 percent of the time. The range of fluctuations as shown in Table 3 indicates small differences in the results when time steps are considered with uniformly distributed inputs.

Case 1 shows that little additional benefit is gained simply by increasing the number of time steps when there is no difference in combat actions between the steps. This result is important in that simply increasing the frequency of measurements does not guarantee more accurate portrayal of the battle. Small variations in the parameters discussed above were caused by more frequent updates of the force sizes as the number of time steps increased.

2. CASE 2

Case 2 examines the possibility of depicting the same 12 hour battle by showing the internal dynamics of this battle. In Case 2, two different scenarios are developed for the purpose of comparison. These scenarios differ in battle postures assumed by the units and the varying times these postures are maintained. In turn, these variables are determined by the characteristics of the battle. In other words, each segment of time in each scenario coincides with a particular battle posture and these postures will result in different parameters generated by ATCAL. The present methodology used at CAA only catalogs a 12 hour battle with one battle posture. The added capability to vary the battle postures within a 12 hour battle is possible with VIC but not with COSAGE.

Because COSAGE is a highly stochastic model, many replications of each 12 hour battle are required to produce average end-of-battle results. Each replicated

battle is likely to consist of different phases occurring in different sequences for varying lengths of time. Therefore, unless only one replication of COSAGE is used to depict a battle, partitioning of the battle into phases is not possible.

On the other hand, VIC is a deterministic model, obviously negating the requirement for replication. Therefore, a VIC battle is amenable to a phased partitioning of the battle using appropriate rules to define the phases. The scenarios for Case 2 described below demonstrate the effects of partitioning a VIC battle to enhance the ATCAL estimators for FORCEM.

A computer simulation was run to determine the variability of parameters (Appendix D). The first step in Case 2, therefore, is to break a 12 hour battle into different time steps, each representing a change in battle posture. For the purposes of Case 2, the battle postures are meeting engagement, static defense, defense, or attack. This partitioning of the battle caused the inputs of rounds fired and attrition to change for each time step. With VIC's smaller time steps, the following inputs into ATCAL will change with each time period: losses (X_{ijk}), rounds fired (RD_{ijk}), and initial forces (N_k). The inputs are then used to compute attrition rate (A_{ijk}), vehicle average (VA_k), vehicle importance (VI_k), and target priority (Q_{ijk}). These computations then allow ATCAL to compute the parameters of probability of kill (P_{ijk}) and availability (AV_{ijk}) as output. With smaller time steps, all the variables and parameters are enhanced because they more accurately reflect the dynamics during that interval of the battle. The parameter changes within time steps for the two different scenarios are described below. In order to emphasize the changes in internal battle dynamics, the end-of-battle losses and rounds fired are fixed for both scenarios.

Scenario 1 is a battle that involves a 2 hour meeting engagement followed by an 8 hour static defense by the blue force and a 2 hour strong defense by the blue force. Scenario 2 involves a 4 hour meeting engagement, followed by a 4 hour static defense by blue and a 4 hour counterattack by the blue force. Obviously, these are quite different 12 hour battles. Therefore, one could not tell by the end results of a battle the dynamics of the various battle postures which occurred. As shown in Table 4, the final number of casualties and rounds fired during the 12 hour battle of these two different scenarios are the same, but the internal parameters per battle posture are quite different.

a. COMPARISONS WITHIN SCENARIO 1 AND SCENARIO 2

In the discussion which follows, the change in parameter values during the battle are described comparing the probability of kill (P_{ijk}) and availability (AV_{ijk}) during each posture in each scenario (Table 4). Recall that the results for the T-72 as firers and the M1 as targets are described in this chapter. In scenario 1, P_{ijk} during the 2 hour meeting engagement, in which units are vulnerable to enemy forces, was 0.25 kills per round. During the next 8 hour static defense posture the units were less susceptible to being killed, and this is reflected by the parameter change to 0.17 kills per round. During the final 2 hour defense posture there was a slight increase in the kill probability to 0.19 kills per round. This could be attributed to any number of factors such as enemy proximity or weapon lethality.

TABLE 4

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M1 IN CASE 2

Time steps	X	RD	P	A	AV	BL
00 - 12	15	84	.18	.025	.018	30
***						
SCENARIO 1 :						
Meeting Engagement						
00 - 02	1	4	.25	.010	.004	48
static Defense						
02 - 10	11	64	.17	.030	.016	34
Defense						
10 - 12	3	16	.19	.040	.018	30
***						
SCENARIO 2 :						
Meeting Engagement						
00 - 04	3	20	.15	.015	.013	46
static defense						
04 - 08	4	35	.11	.023	.016	41
attack						
08 - 12	8	29	.28	.053	.014	30

Next, the availability parameter in scenario 1 between the T-72 firing at M1 tanks is considered. As noted in Table 4, there is a substantial difference in AV_{ijk} between the 2 hour meeting engagement and any of the other battle postures in the the same scenario. This occurred because of the number and distribution of rounds

fired by the T-72 tank. In the 2 hour meeting engagement, the T-72 fired a total of 14 rounds against all targets (M1 and M2) in this example. The total number of rounds is computed by adding the rounds fired in Tables 4 and 5. Of these 14 rounds, only 4 were directed toward the M1 tanks. Because there were 50 T-72 tanks and 50 M1 tanks, the percent of time a single M1 could be fired upon by T-72 firers was very small, the value being 0.4 percent as shown in Table 4. On the other hand, during the static defense posture in Scenario 1, the T-72 fired 129 rounds of which 64 were directed toward the M1. For this example, the maximum rate of fire, $RATE_{ij}$, was assumed to be twice that of the number of rounds fired over the interval. In actuality this value is computed outside the simulation by a rather complex process involving several high resolution simulation runs. Thus, for the static defense, the availability factor increased to 1.6 percent.

TABLE 5

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M2 IN CASE 2

Time steps	X	RD	P	A	AV	BL
00 - 12	25	100	.25	.042	.007	65
**						
SCENARIO 1 :						
Meeting Engagement						
00 - 02	2	10	.20	.020	.005	97
static Defense						
02 - 10	18	65	.28	.049	.007	72
Defense						
10 - 12	5	25	.20	.065	.008	65
**						
SCENARIO 2 :						
Meeting Engagement						
00 - 04	5	25	.20	.025	.006	93
static defense						
04 - 08	5	20	.25	.028	.005	85
attack						
08 - 12	15	55	.27	.095	.007	65

Another observation is that AV_{ijk} for the T-72 firing on the M1 is about one-half that of the M2 as shown in Tables 4 and 5. This was expected since there are twice as many M2 systems on the battlefield yet they received close to the same

number of rounds from the T-72. It is not exactly one-half in this case because of non-linearity of the availability equation (eqn 3.13.). This non-linearity is most evident when examining the 2 hour meeting engagement. The M2 availability was only 0.5 percent because of the small number of rounds fired by the T-72.

In scenario 2 the P_{ijk} during the 4 hour meeting engagement posture was 0.15. During the 4 hour static defense posture the parameter was slightly reduced to 0.11 kills per round. During the final 4 hour blue attack posture the P_{ijk} increased to 0.28 as would be expected since the units are generally more vulnerable in the attack.

In scenario 2, AV_{ijk} exhibited very little change, because the number of rounds fired and the number of M1 and T-72 systems remained proportional. For example, the first two battle postures were very similar in number of rounds fired and vehicle average. In the attack battle posture, the number of rounds increased but VA_i and VA_k decreased. Therefore, in this case the AV_{ijk} value did not change significantly.

b. COMPARISONS BETWEEN SCENARIOS

In comparing scenarios 1 and 2, various parameters depict the varying dynamics of the battle. For example, P_{ijk} during the meeting engagement posture for scenarios 1 and 2 were 0.25 and 0.15, respectively. This difference is attributed to different degrees of enemy contact. In scenario 1, one M1 tank was killed by 4 rounds from T-72 tanks. In scenario 2, three M1's were killed by 20 T-72 tank rounds.

A second example considers the static defense posture of each scenario. Scenario 1 shows the P_{ijk} to be 0.17 kills per round as 11 M1 tanks were killed by 64 T-72 rounds. Although the P_{ijk} was relatively low, a large number of rounds were fired and the attrition rate parameter (A_{ijk}) increased. Therefore, a defense posture was taken for the next phase. In scenario 2 the P_{ijk} parameter was 0.11 kills per round. Since only 4 tanks in 35 rounds were killed in this posture, it is evident that the force met light resistance which influenced the decision to go to the attack posture. This decision is supported by the slight change in the attrition rate.

Comparison of the availability values between the two meeting engagements shows a substantial change (eg., from 0.4 percent in scenario 1 to 1.3 percent in scenario 2). This was primarily due to the significant increase in the number of rounds fired at the M1 tanks in scenario 2 (eg. 4 rounds fired at M1 out of 16 total rounds fired in scenario 1 compared to 20 out of 45 in scenario 2).

c. *COMPARING SCENARIOS TO OVERALL 12 HOUR BATTLE*

Finally, consider a comparison of the two scenarios to the overall 12 hour battle. The values of P_{ijk} and AV_{ijk} for the overall 12 hour battle were 0.18 and 0.018, respectively. These values differ substantially from those for the various phases of the battle, even though the end-of-battle force sizes and rounds fired were held constant for all cases.

The same type of comparisons can be made with the remaining variables and parameters. What is important in these comparisons is that for any one phase of a battle, the overall battle parameters are unable to capture these dynamics. At no time in the different battle scenarios does any of the output parameters of ATCAL Phase I agree with the overall battle parameters. The battle is dynamic and always changing.

As demonstrated, having the ability to vary the inputs for each phase of the battle in VIC represents a potential to enhance FORCEM. The engagements will take different courses of action based on the tactics involved, and the results will be more indicative of the actual battle. Another possibility is to produce a larger inventory of battle results (ATCAL I) to estimate the parameters for FORCEM via ATCAL II which predicts battle results for a similar mix of forces. This larger inventory could provide more insight into the dynamics of the battle and a clearer interpretation of model outputs. Additional runs for each battle phase type could be made to determine whether certain ATCAL parameters can be estimated as a function of battle posture. This would be the same type process that the COMAN model used in determining the three ranges for the MLEs as discussed in Chapter III.

3. CASE 3

FORCEM currently is unable to depict nuclear and chemical effects on the battlefield. The primary reason is that COSAGE does not represent these functions. It is anticipated that these modules will be available in VIC in the near future. With a smaller time step available in VIC, ATCAL Phase I could generate nuclear parameter values to be cataloged for use by FORCEM via ATCAL Phase II. As shown in Case 2, being able to divide the battle into smaller time segments allows consideration of the dynamics of the battle. This will enable military planners to study the effects of utilizing non-conventional warfare in a Division and higher scenario.

A computer simulation was run to demonstrate this case (Appendix E). The blue force is engaged in a 12 hour battle in which a meeting engagement occurs for the first four hours. After the meeting engagement the blue force assumes a defense

posture for 4 hours. Following the defense posture, the blue force is subjected to a nuclear strike that lasts for 1 hour. The last three hours of the 12 hour battle consist of the blue forces being in a defensive posture. In Case 2, scenario 2, the blue force went on the attack for the last 4 hours. As shown in Case 3, the red force required a nuclear strike to maintain the offensive. In this case the blue force was hit by a nuclear attack and was required to assume a defensive posture, since an attack posture was no longer feasible. Table 6 indicates the results of the T-72 firer against M1 targets. Although the nuclear strike destroyed a substantial amount of equipment it does not show in the parameters, but only in the final column of forces remaining. Note, however, that the M1 force size entering the final defense phase is substantially reduced, potentially resulting in a very different battle than if the nuclear strike had not occurred.

The input to ATCAL could be in any size time interval with any type of changing combat mission. At present, the mission is aggregated over a 12 hour time span with no capability of depicting a one time effect over a small time interval, such as the example of a tactical nuclear strike. When the VIC model is able to depict nuclear warfare, these parameter values could be carried throughout the models and be stored as parameter values over a small time step for use in FORCEM.

TABLE 6

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M1 IN CASE 3

Time steps	X	RD	P	A	AV	BL
00 - 12	15	84	.18	.025	.018	30
Meeting Engagement						
00 - 04	3	20	.15	.015	.013	46
Static Defense						
04 - 08	4	20	.20	.023	.016	41
Red NUCLEAR Attack						
08 - 09	0	0	.00	.00	.000	30
Blue Defense						
09 - 12	5	25	.20	.047	.015	20

C. SUMMARY

VIC provides increased information by allowing the battle to be segmented into a number of smaller distinct combat engagements of various types. Analysis of simulation output indicated that while combat output from ATCAL over a 12 hour interval could be reproduced, the combat activities which produced them may vary greatly. Through VIC, these variations in combat activities can be documented and eventually used to greater advantage in FORCEM. The ability of VIC to handle smaller time steps will allow for enhancement in portrayal of combat dynamics not currently available in COSAGE, particularly in areas such as chemical/nuclear warfare.

V. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

Throughout the previous chapters the various methodologies used to incorporate high resolution model results into a low resolution aggregated combat simulation model have been discussed. More specifically, the effect of using the VIC model as the principal model (vice COSAGE) within the current ATCAL/FORCEM model framework was examined in regards to its future potential. While there are additional options in the methods used to develop the input parameters from high resolution model output such as COMAN, the main concern was to investigate those options available within the current ATCAL/FORCEM framework (Fig 1.1). To this end, the salient points observed relevant to the VIC model are presented below.

- VIC's deterministic approach provides a more rapid and less costly methodology of providing high resolution results.
- COSAGE's stochastic structure requires multiple replications to produce end-of-battle results, thus negating the ability to document the battle in phases.
- VIC provides an easily assessible audit trail of combat activity within the specified time intervals, as well as the single roll-up report at 12 hour intervals provided by COSAGE.
- VIC will have the ability to portray non-conventional warfare not currently available in COSAGE.

B. RECOMMENDATIONS FOR FURTHER STUDY

To this point, discussion and analysis of the high resolution / low resolution model interface has been limited to the COSAGE versus VIC input to ATCAL. In-depth analysis of alternative methodologies outside of ATCAL was not pursued. Likewise, the effect of increased information flow from the high resolution feeder model into ATCAL/FORCEM were not examined. To this end, the analytical examination of the parameter fit methodology has only begun. As such, the following partial list of possible research topic areas is proposed as an extension to this study.

- Examination of running VIC at the division level and passing division level information and its effect on FORCEM results.
- Examination of running VIC at the corps level and passing division level information and its effect on FORCEM results.

- Examination of running VIC at the corps and passing corps level information and its effect on FORCEM results.
- Determination of unit size limitations of VIC.
- Comparison of FORCEM output under conditions of division, corps and alternative unit level outputs.
- Determination of the minimum time interval required for ATCAL to produce worthwhile results.

APPENDIX A
COSAGE MODEL

The Combat Sample Generator (COSAGE) is designed to support the analysis of ammunition, personnel, and materiel requirements. COSAGE is a stochastic, high resolution model that produces as output a killer-victim scoreboard. COSAGE is curently the feeder model for FORCEM via ATCAL. COSAGE is a two-sided, symmetrical, high resolution stochastic simulation model of combat between two forces. It is a discrete event simulation, with stochastic phenomenon modeled through events and processes. Typically, the blue force is sized as a division and the red force is scaled from a fraction of a division to a combined-arms army. The model simulates periods (normally 12 hours) of combat and produces expenditures of ammunition by round type and losses of personnel and equipment. Maneuver unit resolution is typically down to blue platoons and red companies. In the case of close combat, resolution is to the individual equipment and weapon level. Within each maneuver unit a heterogeneous list of weapons is maintained. During direct fire engagements, individual weapon systems are arranged in combat formations, interactions between weapon system types are computed, and individual weapons may be stochastically killed. The COSAGE model is an event sequenced simulation using numerous event routines as well as process oriented control structures.

COSAGE allows the user to input two separate process data sets for day and night operations. The model selects the proper data set to use based on the simulation clock. COSAGE also models visibility conditions in considerable detail.

The COSAGE model consists of over 240 processes, events, and routines. The major components of the model are as follows:

1. PREAMBLE - The preamble defines the internal data structure of the model and unifies all of the various components. The model can be thought of as a collection of data representing units, weapons effects, orders, etc. and functions such as unit position updates and equipment attrition can operate asynchronously on this data and modify it.

2. MAIN - The main routine is the driver, and as such causes the model to input the data and then perform the simulation.

3. INPUT ROUTINES - These routines input the model data and perform limited checking on the data, and initialize the model for execution.

4. SMALL UNIT ENGAGEMENTS - These events, processes, and routines control units while engaged in direct fire combat. They position the units in combat formations, cause them to close with the opposite side, and perform combat detections, engagements, and assessment.

5. INDIRECT FIRE - These events, processes, and routines control all aspects of artillery fire mission planning, indirect fire execution, and assessment.

6. OUTPUT ROUTINES - These routines produce the output results of the simulation to allow analysis to be performed.

COSAGE portrays up to 102 different combat related systems with 51 blue systems and 51 red systems. These systems are divided into 7 categories. Each category has a specific set of numbers assigned (see Table 7). For example number 44 represents a blue artillery weapon system such as a M-102 Howitzer and the number 45 represents another blue but different artillery system such as the M-198 Howitzer.

The basic question that the COSAGE model addresses is " If two forces engage in 12 hours of combat, what are the losses of personnel and equipment " ? The output from COSAGE gives a killer-victim scoreboard, rolled-up into specific categories, as shown in Table 7. [Ref. 8]

TABLE 7

COSAGE

CAT #	BLUE WEAPON SYSTEMS	CAT #	RED WEAPON SYSTEMS
1 - 51	blue	52 - 102	red
1 - 12	tanks	52 - 63	tanks
13- 24	armor	64 - 75	armor
25- 29	helicopters	76 - 80	helicopters
30- 41	air defense	81 - 92	air defense
42	personnel	93	personnel
43- 50	artillery	94 - 101	artillery
51	close air support	102	close air support

APPENDIX B
VECTOR-2 MODEL

The VECTOR-2 model was developed in 1976 and represents deterministic ground and air theater combat among several kinds of units. Ground maneuver forces are represented by battalion sized basic maneuver units. Within each aggregated maneuver battalion, VECTOR-2 keeps track of the number of each distinct weapon system (in eleven catagories plus personnel) using a heterogeneous aggregation system. Artillery units, air defense units, fixed wing tactical air units, and helicopter units are represented similarly in terms of the weapon systems they contain. VECTOR-2 is intended to provide information useful in making net assessments and general purpose force tradeoff analysis, and in studies of strategy and tactics in theater-level, mid-intensity campaigns.

VECTOR-2 maintains eight simulation clocks in a nested loop structure. The time step interval for the outermost clock is typically 24 hours. This clock is to update theater planning and force allocations. The remaining clocks have intermediate time step intervals which are used to time combat functions.

VECTOR-2 represents combat among battalions on a theater battlefield. The battlefield representation consists of roughly parallel sectors. The model also allows for environmental conditions to be varied through user input for each sector and each hour of combat. These conditions are combined with the battlefield terrain codes to influence combat processes such as movement and target acquisition.

The approach taken in VECTOR-2 is that the effects of individual weapon system types on the outcome of a theater-level campaign are clearly observable and bear clear relationship to the input performance assumed. The model continually keeps track of the current inventories of personnel and weapon systems by type and location. It also keeps track of the command hierarchy of maneuver forces from theater down to battalion level.

Six types of processes modeled in VECTOR-2 cause dynamic change in value of the state variables. These types are as follows:

1. Firepower processes result in the firepower of one of the opposing sides causing damage to the elements or supplies of the other side. The model computes the attrition of weapon systems by type and personnel for the opposing units at successive ranges as the units maneuver during the engagement. Output of this

model is a complete description of the surviving weapons systems by type and personnel at the end of the combat activity.

2. Command and control processes of decision making in response to situations on the battlefield.
3. Intelligence and target acquisition processes collect information about future events.
4. Communication processes relay information on the battlefield.
5. Logistics processes include the consumption of supply items.
6. Movement processes include the movement of forces on the battlefield.

VECTOR-2 requires the following five types of input:

1. Data which describe the quantitative performance capabilities of the forces, weapon systems, and other resources.
2. Initial force and supply inventory data.
3. Data describing the environment.
4. Tactical decision rules.
5. Initial intelligence information.

Representative model outputs for VIC are as follows:

1. Model time period and cumulative weapon system losses by type.
2. Model time period and cumulative casualties.
3. Supply totals by type of supply.
4. Weather conditions.
5. Total weapon system survivors by weapon type.
6. Acquired targets by type.
7. Information on front line task force.
8. Attrition of casualities and weapon system losses by type .

The representation of maneuver unit combat in VIC belongs to a general combat modeling methodology known as the *differential models of combat.* This approach explicitly includes detailed factors of interest to military planners and has been shown to produce combat predictions essentially identical to those of Monte Carlo simulations (stochastic). Bonder and Farrell developed much of the general methodology and also performed comparisons with detailed Monte Carlo simulations of combat. VECTOR-2 solves the differential equations of combat by approximating them with difference equations. The model approximates the attrition coefficients of the equations as constants over a time interval and approximates the attrition occurring during that time step on the basis of those constant coefficients.

VECTOR-2's representation of the fire support allocation process selects artillery or mortars to engage a particular target and an indirect fire module is called upon to compute the effects of the allocated fire. Two types of fire may be represented :

1. AREA FIRE. The area targeted fire support case is based on a generalized target model originated by John von Neuman. In this model a target's elements are considered to be circular normal distributed about a target center. In VECTOR-2, a target under attack is considered to be composed of several widely seperated subtargets, each seperately attackable. Each attack is assumed to have a circular normal delivery error about the subtarget center. The effect of each pattern of fire delivered during an attack is described by a diffused Gaussian damage function,

$$nn_i = (1-(1-D_i)^N)n_i \qquad \text{(eqn B.1)}$$

   where

   nn_i = the number of target elements of type i destroyed.

   D_i = the fractional damage to a type-i element in a subtarget per attack on that subtarget.

   n_i = the number of type-i elements in the target before the attack.

   N = the number of attacks conducted against a single subtarget.

2. INDIVIDUALLY TARGETED FIRE is shown by the following equation

$$nn_i = M \Sigma_l (K_{il} \times P_{il} \times F_i) \qquad \text{(eqn B.2)}$$

   where

   nn_i is the attrition to target elements of type i.

   K_{il} = the probability a target element of type i in posture class l is destroyed by a single item of ordanance.

   P_{il} = the fraction of target elements of type i in posture class l.

   F_i = the probability a target element of type i is chosen.

   M = the number of ordinance items.

In summary, VECTOR-2 is a combat model developed in 1976 which represents deterministic group and air theater combat. It uses difference equations to approximate attrition and battle results. The VECTOR-2 model is a forerunner of the VIC model that will be replacing COSAGE as the feeder model for FORCEM. [Ref. 9]

APPENDIX C

APL PROGRAM FOR ATCAL POINT FIRE (CASE 1)

```
     ∇ATCAL[⎕]∇
     ∇ ATCAL
[1]  ⍝ PURPOSE : TO WRITE AN APL PROGRAM FOR POINT FIRE ATCAL PHASE I.
[2]  ⍝ INPUT VALUES, FORCE SIZE, ATTRITION, AND FIRING MATRIX
[3]  ⍝ CASE 1
[4]  'PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES'
[5]  BL←⎕
[6]  'PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES'
[7]  R←⎕
[8]  ⍝'PLEASE ENTER TIME STEP IN HOURS'
[9]  ⍝T←⎕
[10] ⍝PKB← 0.18 0.36 0.25 0.43
[11] ⍝PKR← 0.11 0.42 0.19 0.16
[12] RDR← 84 14 100 24
[13] RDB← 90 12 80 32
[14] ⍝'PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES'
[15] ⍝XB←⎕
[16] ⍝'PLEASE ENTER RED ATTRITION DURING PERIOD, 4 VALUES'
[17] ⍝XR←⎕
[18] ⍝'PLEASE ENTER RED FIRING MATRIX FOR PERIOD, 4 VALUES'
[19] ⍝RDR←⎕
[20] ⍝'PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD, 4 VALUES'
[21] ⍝RDB←⎕
[22] XB← 15 5 25 10
[23] XR← 10 5 15 5
[24] T←12
[25] RDB← 2 2 ⍴RDB
[26] RDR← 2 2 ⍴RDR
[27] XB← 2 2 ⍴XB
[28] XR← 2 2 ⍴XR
[29]
[30] ⍝ COMPUTE PROBABILITY OF SINGLE SHOT KILL
[31] ⍝ PROBABILITY BLUE KILLED
[32] PKB←XB÷RDR
[33] ⍝ PROBABILITY OF RED KILLED
[34] PKR←XR÷RDB
[35]
[36] ⍝ COMPUTE ATTRITION (LOSSES)
[37] R1←R,R
[38] R1← 2 2 ⍴R1
[39] A←XB÷(R1×T)
[40] BL1←BL,BL
[41] BL1← 2 2 ⍴BL1
[42] B←XR÷(BL1×T)
[43]
[44] ⍝ COMPUTE VEHICLE AVERAGES
[45] VAB←-(+/XB)÷(⍟(1-((+/XB)÷BL)))
[46] VAR←-(+/XR)÷(⍟(1-((+/XR)÷R)))
[47]
[48] ⍝ VEHICLE IMPORTANCE
[49] VIR←(((+/A)*3)÷(+/XB)×(R*2))*0.33333
[50] VIB←(((+/B)*3)÷(+/XR)×(BL*2))*0.33333
[51]
[52]
[53] ⍝ COMPUTE PRIORITY VALUES
[54] QB←PKB×(+/VIB)
[55] QR←PKR×(+/VIR)
[56]
[57] ⍝ COMPUTE TARGET AVAILABILITY
[58]
[59] RDR1←RDR÷T
```

```
[60] RDB1←RDB÷T
[61] VAB1←VAB÷T
[62] VAR1←VAR÷T
[63] ' '
[64] Z1←2×(+/RDR)÷R
[65] Z2←2×(+/RDB)÷BL
[66] AVALB←1-(1-(RDR[;1]÷(Z1×VAR)))*(1÷VAB)
[67] AVALR←1-(1-(RDB[;1]÷(Z2×VAB)))*(1÷VAR)
[68] ' INPUTS INTO ATCAL FROM VIC'
[69] ' '
[70] 'INITIAL BLUE FORCE SIZE'
[71] ' '
[72] 'M1 M2'
[73] ' '
[74] BL
[75] ' '
[76] 'INITIAL RED FORCE SIZE'
[77] ' '
[78] 'T-72 AT-5'
[79] ' '
[80] R
[81] ' '
[82] ' BLUE ATTRITION DURING PERIOD'
[83] ' '
[84] 'T-72  AT-5 '
[85] ' '
[86] XB
[87] ' '
[88] ' RED ATTRITION DURING PERIOD'
[89] ' '
[90] ' M1 M2 '
[91] ' '
[92] XR
[93] ' '
[94] 'NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD'
[95] ' '
[96] 'T-72 AT-5'
[97] ' '
[98] RDR
[99] 'NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD'
[100] ' '
[101] ' M1 M2 '
[102] ' '
[103] RDB
[104] ' '
[105] ' OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY'
[106] ' '
[107] ' SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.'
[108] ' '
[109] ' T-72  AT-5 '
[110] ' '
[111] PKB
[112] ' '
[113] 'SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.'
[114] ' '
[115] ' M1 M2'
[116] ' '
[117] PKR
[118] ' '
[119] 'NUMBER OF I KILLED BY EACH J IN K '
[120] ' '
[121] ' T-72  AT-5'
[122] ' '
[123] A
[124] ' '
[125] 'NUMBER OF J KILLED BY EACH I IN K.'
[126] ' '
[127] 'M1 M2'
[128] ' '
[129] B
```

```
[130] ' '
[131] 'VAB'
[132] ' '
[133] VAB
[134] ' VAR '
[135] ' '
[136] VAR
[137] ' AVALIBILITY OF BLUE'
[138] ' '
[139] AVALB
[140] ' '
[141] 'AVALIBILITY OF RED'
[142] ' '
[143] AVALR
[144] ' '
[145] ' COMPUTE END RESULTS OF BATTLE'
[146] ' '
[147] ' BLUE FORCE SIZE '
[148] ' '
[149] ' M1  M2 '
[150] ' '
[151] BL←BL-(+/XB)
[152] BL
[153] ' '
[154] ' RED FORCE SIZE '
[155] ' '
[156] ' T-72  AT-5 '
[157] ' '
[158] R←R-(+/XR)
[159] R
***************************************************************
ONE 12 HOUR BATTLE
       ∇
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
50 100
INITIAL RED FORCE SIZE
T-72 AT-5
50 100
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 15  5
 25 10
 RED ATTRITION DURING PERIOD
  M1  M2
 10  5
 15  5
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
  84  14
 100  24
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
```

```
 M1  M2
 90 12
 80 32
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3571428571
 0.25     0.4166666667
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1111111111 0.4166666667
 0.1875    0.15625
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.025     0.004166666667
 0.04166666667 0.008333333333
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.01666666667 0.004166666667
 0.025     0.004166666667
VAB
39.15230378 81.24741881
 VAR
42.05509878 89.62840235
 AVALIBILITY OF BLUE
0.01803113461 0.007328694237
AVALIBILITY OF RED
0.01951367409 0.006439836553
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
30 65
 RED FORCE SIZE
 T-72  AT-5
35 80
*******************************************************************************
2 SIX HOUR BATTLES
      ∇ATCAL
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
50 100
INITIAL RED FORCE SIZE
T-72 AT-5
```

```
50 100
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
  7.5 2.5
 12.5 5
 RED ATTRITION DURING PERIOD
  M1  M2
 5  2.5
 7.5 2.5
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 42 7
 50 12
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 45 6
 40 16
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3571428571
 0.25     0.4166666667
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1111111111 0.4166666667
 0.1875    0.15625
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.025     0.004166666667
 0.04166666667 0.008333333333
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.01666666667 0.004166666667
 0.025     0.004166666667
VAB
44.81420118 90.96963054
 VAR
46.14847035 94.91221581
 AVALIBILITY OF BLUE
0.01383328234 0.006061696613
AVALIBILITY OF RED
0.01457841222 0.005239088526
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
40 82.5
 RED FORCE SIZE
 T-72  AT-5
42.5 90
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
```

```
⎕:
      40 82.5
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      42.5 90
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
40 82.5
INITIAL RED FORCE SIZE
T-72 AT-5
42.5 90
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
  7.5 2.5
 12.5 5
 RED ATTRITION DURING PERIOD
  M1  M2
 5  2.5
 7.5 2.5
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 42  7
 50 12
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 45  6
 40 16
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3571428571
 0.25     0.4166666667
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1111111111 0.4166666667
 0.1875    0.15625
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.02941176471 0.00462962963
 0.04901960784 0.009259259259
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.02083333333 0.005050505051
 0.03125    0.005050505051
VAB
34.76059497 73.40264618
 VAR
38.62872866 84.90187016
 AVALIBILITY OF BLUE
0.01817974641 0.007568149627
AVALIBILITY OF RED
```

```
0.01817700881 0.006026068321
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
30 65
 RED FORCE SIZE
 T-72  AT-5
35 80
**********************************************************************
3 FOUR HOUR BATTLES
        ∇ATCAL
        ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
        50 100
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
        50 100
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
50 100
INITIAL RED FORCE SIZE
T-72 AT-5
50 100
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 5  1.67
 8.33 3.33
 RED ATTRITION DURING PERIOD
  M1  M2
 3.33 1.67
 5  1.67
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 28   4.67
 33.33 8
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 30   4
 26.67 10.67
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3576017131
 0.2499249925 0.41625
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.111    0.4175
 0.1874765654 0.1565135895
NUMBER OF I KILLED BY EACH J IN K
```

```
 T-72  AT-5
 0.025  0.004175
 0.04165 0.008325
NUMBER OF J KILLED BY EACH I IN K.
M1 M2
 0.01665 0.004175
 0.025  0.004175
VAB
46.5854442 94.04956636
 VAR
47.45610791 96.62663466
 AVALIBILITY OF BLUE
0.01280897064 0.005725984028
AVALIBILITY OF RED
0.01342740355 0.004930356866
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1 M2
43.33 88.34
 RED FORCE SIZE
 T-72  AT-5
45 93.33
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      43.33 88.34
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      45 93.33
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
43.33 88.34
INITIAL RED FORCE SIZE
T-72 AT-5
45 93.33
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 5  1.67
 8.33 3.33
 RED ATTRITION DURING PERIOD
  M1 M2
 3.33 1.67
 5  1.67
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 28  4.67
 33.33 8
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1 M2
 30  4
```

```
 26.67 10.67
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3576017131
 0.2499249925 0.41625
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.111     0.4175
 0.1874765654 0.1565135895
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.02777777778 0.004473374049
 0.04627777778 0.008919961427
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.01921301639 0.004726058411
 0.02884837295 0.004726058411
VAB
39.9021307 82.37250446
 VAR
42.45093508 89.95378919
 AVALIBILITY OF BLUE
0.01506283713 0.006556934175
AVALIBILITY OF RED
0.01524509301 0.005353698193
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
36.66 76.68
 RED FORCE SIZE
 T-72  AT-5
40 86.66
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      36.66 76.68
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      40 86.66
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
36.66 76.68
INITIAL RED FORCE SIZE
T-72 AT-5
40 86.66
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 5  1.67
 8.33 3.33
```

```
 RED ATTRITION DURING PERIOD
  M1 M2
 3.33 1.67
 5   1.67
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
 28   4.67
 33.33 8
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1 M2
 30   4
 26.67 10.67
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3576017131
 0.2499249925 0.41625
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1 M2
 0.111    0.4175
 0.1874765654 0.1565135895
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.03125    0.004817678283
 0.0520625   0.009606508193
NUMBER OF J KILLED BY EACH I IN K.
M1 M2
 0.0227086743  0.005444705269
 0.03409710857 0.005444705269
VAB
33.21345126 70.6898001
 VAR
37.44437845 83.28048763
 AVALIBILITY OF BLUE
0.01825974908 0.007666118098
AVALIBILITY OF RED
0.01766576195 0.005866699775
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1 M2
29.99 65.02
 RED FORCE SIZE
 T-72  AT-5
35 79.99
**********************************************************************
6 TWO HOUR BATTLES
      ∇ATCAL
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
```

```
⎕:
      50 100
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
50 100
INITIAL RED FORCE SIZE
T-72 AT-5
50 100
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 2.5  0.833
 4.17 1.67
 RED ATTRITION DURING PERIOD
  M1  M2
 1.67 0.833
 2.5  0.833
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 14   2.33
 16.67 4
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 15   2
 13.33 5.33
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3575107296
 0.25014997  0.4175
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1113333333 0.4165
 0.1875468867 0.1562851782
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.008333333333 0.001388333333
 0.0139     0.002783333333
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.005566666667 0.001388333333
 0.008333333333 0.001388333333
VAB
48.31434073 97.05071674
 VAR
48.73778837 98.32408498
 AVALIBILITY OF BLUE
0.01192048512 0.005423908752
AVALIBILITY OF RED
0.01243496365 0.004656568117
 COMPUTE END RESULTS OF BATTLE
```

```
 BLUE FORCE SIZE
 M1  M2
46.667 94.16
 RED FORCE SIZE
 T-72  AT-5
47.497 96.667
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      46.667 94.16
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      47.497 96.667
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
46.667 94.16
INITIAL RED FORCE SIZE
T-72 AT-5
47.497 96.667
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 2.5  0.833
 4.17 1.67
 RED ATTRITION DURING PERIOD
  M1  M2
 1.67 0.833
 2.5  0.833
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 14   2.33
 16.67 4
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 15   2
 13.33 5.33
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3575107296
 0.25014997  0.4175
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1113333333 0.4165
 0.1875468867 0.1562851782
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.008772483876 0.001436201944
 0.01463250311 0.002879300416
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
```

```
 0.005964243113 0.001474440668
 0.008928507654 0.001474440668
VAB
44.97992068 91.20884141
 VAR
46.23420839 94.99075461
 AVALIBILITY OF BLUE
0.01282226102 0.005774786669
AVALIBILITY OF RED
0.01314929988 0.004831231219
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
43.334 88.32
 RED FORCE SIZE
 T-72  AT-5
44.994 93.334
       43.334 88.32
43.334 88.32
       ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
       43.334 88.32
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
       44.994 93.334
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
43.334 88.32
INITIAL RED FORCE SIZE
T-72 AT-5
44.994 93.334
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 2.5  0.833
 4.17 1.67
 RED ATTRITION DURING PERIOD
  M1  M2
 1.67 0.833
 2.5  0.833
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 14   2.33
 16.67 4
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 15   2
 13.33 5.33
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
```

```
 0.1785714286 0.3575107296
 0.25014997  0.4175
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1113333333 0.4165
 0.1875468867 0.1562851782
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.009260493992 0.001487489375
 0.01544650398 0.002982121556
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.006422978108 0.001571935386
 0.009615236689 0.001571935386
VAB
41.64527318 85.36670937
 VAR
43.730562 91.65740021
 AVALIBILITY OF BLUE
0.01387048346 0.006173908265
AVALIBILITY OF RED
0.01395275487 0.00502025369
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
40.001 82.48
 RED FORCE SIZE
 T-72  AT-5
42.491 90.001
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      40.001 82.48
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      42.491 90.001
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
40.001 82.48
INITIAL RED FORCE SIZE
T-72 AT-5
42.491 90.001
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 2.5  0.833
 4.17 1.67
 RED ATTRITION DURING PERIOD
  M1  M2
 1.67 0.833
 2.5  0.833
```

```
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
 14   2.33
 16.67 4
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1 M2
 15   2
 13.33 5.33
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3575107296
 0.25014997  0.4175
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1113333333 0.4165
 0.1875468867 0.1562851782
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.009805998133 0.001542575453
 0.01635640489  0.003092558231
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.006958159379 0.00168323634
 0.01041640626  0.00168323634
VAB
38.31033879 79.52426401
 VAR
41.22683708 88.32401906
 AVALIBILITY OF BLUE
0.01510373831 0.006631921904
AVALIBILITY OF RED
0.01486369651 0.005225651559
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
36.668 76.64
 RED FORCE SIZE
 T-72  AT-5
39.988 86.668
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      36.668 76.64
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      39.988 86.668
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
36.668 76.64
INITIAL RED FORCE SIZE
```

T-72 AT-5

39.988 86.668

BLUE ATTRITION DURING PERIOD

T-72 AT-5

2.5 0.833
4.17 1.67

RED ATTRITION DURING PERIOD

M1 M2

1.67 0.833
2.5 0.833

NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD

T-72 AT-5

14 2.33
16.67 4

NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD

M1 M2

15 2
13.33 5.33

OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY

SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.

T-72 AT-5

0.1785714286 0.3575107296
0.25014997 0.4175

SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.

M1 M2

0.1113333333 0.4165
0.1875468867 0.1562851782

NUMBER OF I KILLED BY EACH J IN K

T-72 AT-5

0.0104197926 0.001601898432
0.01738021406 0.003211489054

NUMBER OF J KILLED BY EACH I IN K.

M1 M2

0.007590633068 0.001811499652
0.01136322316 0.001811499652

VAB

34.97503539 73.68143077

VAR

38.72301841 84.99060801

AVALIBILITY OF BLUE

0.01657540062 0.007162852832

AVALIBILITY OF RED

0.01590615039 0.005449889515

COMPUTE END RESULTS OF BATTLE

BLUE FORCE SIZE

M1 M2

33.335 70.8

RED FORCE SIZE

T-72 AT-5

37.485 83.335

```
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      33.335 70.8
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      37.485 83.335
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
33.335 70.8
INITIAL RED FORCE SIZE
T-72 AT-5
37.485 83.335
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 2.5  0.833
 4.17 1.67
 RED ATTRITION DURING PERIOD
  M1  M2
 1.67 0.833
 2.5  0.833
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
 14   2.33
 16.67 4
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1 M2
 15   2
 13.33 5.33
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1785714286 0.3575107296
 0.25014997  0.4175
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.1113333333 0.4165
 0.1875468867 0.1562851782
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.01111555733 0.001665966681
 0.01854074963 0.003339933201
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.008349582521 0.001960922787
 0.01249937503 0.001960922787
VAB
31.63924616 67.83810935
 VAR
36.21908654 81.65716339
 AVALIBILITY OF BLUE
```

```
0.01836144293 0.007785556134
AVALIBILITY OF RED
0.01711229141 0.005696033583
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
30.002 64.96
 RED FORCE SIZE
 T-72  AT-5
34.982 80.002
```

APPENDIX D

APL PROGRAM FOR CASE 2 BATTLE POSTURES IN ATCAL I

```
      ∇ATCAL[⎕]∇
      ∇ ATCAL
  ⍝ PURPOSE : TO WRITE AN APL PROGRAM FOR POINT FIRE ATCAL PHASE I.
  ⍝ INPUT VALUES, FORCE SIZE, ATTRITION, AND FIRING MATRIX
  ⍝ CASE 2
   'PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES'
   BL←⎕
   'PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES'
   R←⎕
   'PLEASE ENTER TIME STEP IN HOURS'
   T←⎕
  ⍝PKB← 0.18 0.36 0.25 0.43
  ⍝PKR← 0.11 0.42 0.19 0.16
  ⍝RDR← 14 2.33 16.67 4
  ⍝RDB← 15 2 13.33 5.33
   'PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES'
   XB←⎕
   'PLEASE ENTER RED ATTRITION DURING PERIOD, 4 VALUES'
   XR←⎕
   'PLEASE ENTER RED FIRING MATRIX FOR PERIOD, 4 VALUES'
   RDR←⎕
   'PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD, 4 VALUES'
   RDB←⎕
  ⍝XB← 2.5 0.833 4.17 1.67
  ⍝XR← 1.67 0.833 2.5 0.833
  ⍝T←6
   RDB← 2 2 ⍴RDB
   RDR← 2 2 ⍴RDR
   XB← 2 2 ⍴XB
   XR← 2 2 ⍴XR

  ⍝ COMPUTE PROBABILITY OF SINGLE SHOT KILL
  ⍝ PROBABILITY BLUE KILLED
   PKB←XB÷RDR
  ⍝ PROBABILITY OF RED KILLED
   PKR←XR÷RDB

  ⍝ COMPUTE ATTRITION (LOSSES)
   R1←R,R
   R1← 2 2 ⍴R1
   A←XB÷(R1×T)
   BL1←BL,BL
   BL1← 2 2 ⍴BL1
   B←XR÷(BL1×T)

  ⍝ COMPUTE VEHICLE AVERAGES
   VAB←-(+/XB)÷(⍟(1-((+/XB)÷BL)))
   VAR←-(+/XR)÷(⍟(1-((+/XR)÷R)))

  ⍝ VEHICLE IMPORTANCE
   VIR←(((+/A)*3)÷(+/XB)×(R*2))*0.33333
   VIB←(((+/B)*3)÷(+/XR)×(BL*2))*0.33333


  ⍝ COMPUTE PRIORITY VALUES
   QB←PKB×(+/VIB)
   QR←PKR×(+/VIR)

  ⍝ COMPUTE TARGET AVAILABILITY

   RDR1←RDR÷T
```

```
[60] RDB1←RDB÷T
[61] VAB1←VAB÷T
[62] VAR1←VAR÷T
[63] ' '
[64] Z1←2×(+/RDR)÷R
[65] Z2←2×(+/RDB)÷BL
[66] AVALB←1-(1-(RDR[;1]÷(Z1×VAR)))*(1÷VAB)
[67] AVALR←1-(1-(RDB[;1]÷(Z2×VAB)))*(1÷VAR)
[68] ' INPUTS INTO ATCAL FROM VIC'
[69] ' '
[70] 'INITIAL BLUE FORCE SIZE'
[71] ' '
[72] 'M1 M2'
[73] ' '
[74] BL
[75] ' '
[76] 'INITIAL RED FORCE SIZE'
[77] ' '
[78] 'T-72 AT-5'
[79] ' '
[80] R
[81] ' '
[82] ' BLUE ATTRITION DURING PERIOD'
[83] ' '
[84] 'T-72  AT-5 '
[85] ' '
[86] XB
[87] ' '
[88] ' RED ATTRITION DURING PERIOD'
[89] ' '
[90] ' M1  M2 '
[91] ' '
[92] XR
[93] ' '
[94] 'NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD'
[95] ' '
[96] 'T-72  AT-5'
[97] ' '
[98] RDR
[99] 'NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD'
[100] ' '
[101] ' M1  M2 '
[102] ' '
[103] RDB
[104] ' '
[105] ' OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILIT
[106] ' '
[107] ' SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.'
[108] ' '
[109] ' T-72  AT-5 '
[110] ' '
[111] PKB
[112] ' '
[113] 'SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.'
[114] ' '
[115] ' M1  M2'
[116] ' '
[117] PKR
[118] ' '
[119] 'NUMBER OF I KILLED BY EACH J IN K '
[120] ' '
[121] ' T-72  AT-5'
[122] ' '
[123] A
[124] ' '
[125] 'NUMBER OF J KILLED BY EACH I IN K.'
[126] ' '
[127] 'M1 M2'
[128] ' '
[129] B
```

```
[130] ' '
[131] 'VAB'
[132] ' '
[133] VAB
[134] ' VAR '
[135] ' '
[136] VAR
[137] ' AVALIBILITY OF BLUE'
[138] ' '
[139] AVALB
[140] ' '
[141] 'AVALIBILITY OF RED'
[142] ' '
[143] AVALR
[144] ' '
[145] ' COMPUTE END RESULTS OF BATTLE'
[146] ' '
[147] ' BLUE FORCE SIZE '
[148] ' '
[149] ' M1  M2 '
[150] ' '
[151] BL←BL-(+/XB)
[152] BL
[153] ' '
[154] ' RED FORCE SIZE '
[155] ' '
[156] ' T-72  AT-5 '
[157] ' '
[158] R←R-(+/XR)
[159] R
      ∇
2 HOUR MEETING ENGAGEMENT
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      50 100
PLEASE ENTER TIME STEP IN HOURS
⎕:
      2
PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES
⎕:
      1 1 2 1
PLEASE ENTER RED ATTRITION DURING PERIOD, 4 VALUES
⎕:
      3 1 4 1
PLEASE ENTER RED FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
      4 7 10 3
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
      20 3 20 8
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
50 100
INITIAL RED FORCE SIZE
T-72 AT-5
50 100
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 1 1
```

```
 2 1
 RED ATTRITION DURING PERIOD
  M1 M2
 3 1
 4 1
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
  4 7
 10 3
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1 M2
 20 3
 20 8
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.25     0.1428571429
 0.2     0.3333333333
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1 M2
 0.15     0.3333333333
 0.2     0.125
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.01 0.005
 0.02 0.005
NUMBER OF J KILLED BY EACH I IN K.
M1 M2
 0.03 0.005
 0.04 0.005
VAB
48.99319652 98.49238532
 VAR
47.97220935 97.47862873
 AVALIBILITY OF BLUE
0.004279340403 0.005081915131
AVALIBILITY OF RED
0.01215095836 0.00460956574
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1 M2
48 97
 RED FORCE SIZE
 T-72  AT-5
46 95
*************************************************************************
8 HOUR STATIC DEFENSE
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      48 97
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
```

```
⎕:
      46 95
PLEASE ENTER TIME STEP IN HOURS
⎕:
      8
PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES
⎕:
      11 3 18 7
PLEASE ENTER RED ATTRITION DURING PERIOD, 4 VALUES
⎕:
      4 3 7 3
PLEASE ENTER RED FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
      64 7 65 15
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
      50 6 40 16
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
48 97
INITIAL RED FORCE SIZE
T-72 AT-5
46 95
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 11  3
 18  7
 RED ATTRITION DURING PERIOD
  M1  M2
 4 3
 7 3
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 64  7
 65 15
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 50  6
 40 16
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.171875    0.4285714286
 0.2769230769 0.4666666667
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.08  0.5
 0.175 0.1875
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.02989130435 0.003947368421
 0.04891304348 0.009210526316
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
```

```
 0.01041666667 0.003865979381
 0.01822916667 0.003865979381
VAB
40.5984812 83.87999056
 VAR
42.40374719 89.90733108
 AVALIBILITY OF BLUE
0.01639782634 0.006663727006
AVALIBILITY OF RED
0.01754062557 0.00590790278
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
34 72
 RED FORCE SIZE
 T-72  AT-5
39 85

************************************************************************
2 HOUR DEFENSE
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
□:
      34 72
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
□:
      39 85
PLEASE ENTER TIME STEP IN HOURS
□:
      2
PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES
□:
      3 1 5 2
PLEASE ENTER RED ATTRITION DURING PERIOD,  4 VALUES
□:
      3 1 4 1
PLEASE ENTER RED FIRING MATRIX FOR PERIOD,  4 VALUES
□:
      16 3 25 6
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD,  4 VALUES
□:
      20 3 20 8
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
34 72
INITIAL RED FORCE SIZE
T-72 AT-5
39 85
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 3 1
 5 2
 RED ATTRITION DURING PERIOD
  M1  M2
```

```
 3 1
 4 1
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 16  3
 25  6
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 20  3
 20  8
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1875    0.3333333333
 0.2      0.3333333333
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.15      0.3333333333
 0.2      0.125
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.03846153846 0.005882352941
 0.0641025641  0.01176470588
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.04411764706 0.006944444444
 0.05882352941 0.006944444444
VAB
31.95828984 68.44034774
 VAR
36.96393584 82.47474129
 AVALIBILITY OF BLUE
0.01821318695 0.007817311618
AVALIBILITY OF RED
0.01665815038 0.005696413431
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
30 65
 RED FORCE SIZE
 T-72  AT-5
35 80
*******************************************************************
*******************************************************************
         SCENARIO 2
                  ^
4 HOUR MEETING ENGAGEMENT
         ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
         50 100
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
```

```
        50 100
PLEASE ENTER TIME STEP IN HOURS
⎕:
        4
PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES
⎕:
        3 1 5 2
PLEASE ENTER RED ATTRITION DURING PERIOD, 4 VALUES
⎕:
        3 1 4 1
PLEASE ENTER RED FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
        20 3 25 6
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
        20 3 20 8
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
50 100
INITIAL RED FORCE SIZE
T-72 AT-5
50 100
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 3 1
 5 2
 RED ATTRITION DURING PERIOD
  M1  M2
 3 1
 4 1
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72  AT-5
 20  3
 25  6
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 20  3
 20  8
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.15      0.3333333333
 0.2      0.3333333333
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.15      0.3333333333
 0.2      0.125
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.015 0.0025
 0.025 0.005
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
```

```
 0.015 0.0025
 0.02  0.0025
VAB
47.97220935 96.45767081
 VAR
47.97220935 97.47862873
 AVALIBILITY OF BLUE
0.01250347326 0.005519243485
AVALIBILITY OF RED
0.01250347326 0.004732841213
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
46 93
 RED FORCE SIZE
 T-72  AT-5
46 95
***************************************************************************
4 HOUR STATIC DEFENSE
        ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
        46 93
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
        46 95
PLEASE ENTER TIME STEP IN HOURS
⎕:
        4
PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES
⎕:
        4 1 5 3
PLEASE ENTER RED ATTRITION DURING PERIOD,  4 VALUES
⎕:
        4 3 7 3
PLEASE ENTER RED FIRING MATRIX FOR PERIOD,  4 VALUES
⎕:
        40 3 20 9
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD,  4 VALUES
⎕:
        40 6 40 6
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
46 93
INITIAL RED FORCE SIZE
T-72 AT-5
46 95
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
 4 1
 5 3
 RED ATTRITION DURING PERIOD
  M1  M2
 4 3
```

```
 7 3
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
 40 3
 20 9
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1 M2
 40 6
 40 6
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.1      0.3333333333
 0.25      0.3333333333
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1 M2
 0.1  0.5
 0.175 0.5
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.02173913043 0.002631578947
 0.02717391304 0.007894736842
NUMBER OF J KILLED BY EACH I IN K.
M1 M2
 0.02173913043 0.008064516129
 0.03804347826 0.008064516129
VAB
43.45206502 88.94004259
 VAR
42.40374719 89.90733108
 AVALIBILITY OF BLUE
0.01603305085 0.005081742077
AVALIBILITY OF RED
0.01443827571 0.006720815081
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1 M2
41 85
 RED FORCE SIZE
 T-72  AT-5
39 85
*****************************************************************
4 HOUR ATTACK
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      41 85
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 2 VALUES
⎕:
      39 85
PLEASE ENTER TIME STEP IN HOURS
⎕:
      4
```

```
PLEASE ENTER BLUE ATTRITION DURING PERIOD, 4 VALUES
⎕:
      8 3 15 5
PLEASE ENTER RED ATTRITION DURING PERIOD, 4 VALUES
⎕:
      3 1 4 1
PLEASE ENTER RED FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
      24 8 55 9
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD, 4 VALUES
⎕:
      50 3 20 8
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
M1 M2
41 85
INITIAL RED FORCE SIZE
T-72 AT-5
39 85
 BLUE ATTRITION DURING PERIOD
T-72  AT-5
  8  3
 15  5
 RED ATTRITION DURING PERIOD
  M1  M2
 3 1
 4 1
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
T-72 AT-5
 24  8
 55  9
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
 M1  M2
 50  3
 20  8
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
 T-72  AT-5
 0.3333333333 0.375
 0.2727272727 0.5555555556
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2
 0.06     0.3333333333
 0.2     0.125
NUMBER OF I KILLED BY EACH J IN K
 T-72  AT-5
 0.05128205128 0.008823529412
 0.09615384615 0.01470588235
NUMBER OF J KILLED BY EACH I IN K.
M1  M2
 0.01829268293 0.002941176471
 0.0243902439  0.002941176471
VAB
```

```
35.21412114 74.55342871
 VAR
36.96393584 82.47474129
 AVALIBILITY OF BLUE
0.01419963028 0.007814816806
AVALIBILITY OF RED
0.02132370462 0.006319768911
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2
30 65
 RED FORCE SIZE
 T-72  AT-5
35 80
     ∇ATCAL
```

APPENDIX E

ATCAL NUCLEAR BATTLE (CASE 3)

```
      ∇ATCAL[⎕]∇
      ∇ ATCAL
[1]  ⍝ PURPOSE : TO WRITE AN APL PROGRAM FOR POINT FIRE ATCAL PHASE I.
[2]  ⍝ INPUT VALUES, FORCE SIZE, ATTRITION, AND FIRING MATRIX
[3]  ⍝ CASE 3
[4]   'PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 3 VALUES'
[5]   BL←⎕
[6]   'PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 3 VALUES'
[7]   R←⎕
[8]   'PLEASE ENTER BLUE ATTRITION DURING PERIOD,  9 VALUES'
[9]   XB←⎕
[10]  'PLEASE ENTER RED ATTRITION DURING PERIOD,  9 VALUES'
[11]  XR←⎕
[12]  'PLEASE ENTER RED FIRING MATRIX FOR PERIOD,  9 VALUES'
[13]  RDR←⎕
[14]  'PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD,  9 VALUES'
[15]  RDB←⎕
[16]  'PLEASE ENTER TIME STEP IN HOURS'
[17]  T←⎕
[18]  RDB← 3 3 ⍴RDB
[19]  RDR← 3 3 ⍴RDR
[20]  XB← 3 3 ⍴XB
[21]  XR← 3 3 ⍴XR
[22]
[23] ⍝ COMPUTE PROBABILITY OF SINGLE SHOT KILL (KILL PER ROUND)
[24] ⍝ PROBABILITY OF BLUE KILLED
[25]  PKB←XB÷RDR
[26] ⍝ PROBABILITY OF RED KILLED
[27]  PKR←XR÷RDB
[28]
[29] ⍝ COMPUTE ATTRITION
[30]  R1←R,R
[31]  R1← 3 3 ⍴R1
[32]  A←XB÷(R1×T)
[33]  BL1←BL,BL
[34]  BL1← 3 3 ⍴BL1
[35]  B←XR÷(BL1×T)
[36]
[37] ⍝ COMPUTE VEHICLE AVERAGES
[38]  VAB←-(+/XB)÷(⍟(1-((+/XB)÷BL)))
[39]  VAR←-(+/XR)÷(⍟(1-((+/XR)÷R)))
[40]
[41] ⍝ VEHICLE IMPORTANCE
[42]  VIR←(((+/A)*3)÷(+/XB)×(R*2))*0.33333
[43]  VIB←(((+/B)*3)÷(+/XR)×(BL*2))*0.33333
[44]
[45]
[46] ⍝ COMPUTE PRIORITY VALUES
[47]  QB←PKB×(+/VIB)
[48]  QR←PKR×(+/VIR)
[49]
[50] ⍝ COMPUTE TARGET AVAILABILITY
       Z1 2  (+/RDR) R
-51-  Z2 2  (+/RDB) BL
-52-  AVALB-1-(1-(RDR ;1  (Z1 VAR)))*(1 VAB)
-53-  AVALR-1-(1-(RDB 1;  (Z1 VAB)))*(1-VAR)
[54]  ' INPUTS INTO ATCAL FROM VIC'
[55]  ' '
[56]  'INITIAL BLUE FORCE SIZE'
[57]  ' '
[58]  BL
```

```
[59]  ' '
[60]  ' M1 M2 NUC'
[61]  ' '
[62]  'INITIAL RED FORCE SIZE'
[63]  ' '
[64]  ' T-72 AT-5 NUC'
[65]  ' '
[66]  R
[67]  ' '
[68]  ' BLUE ATTRITION DURING PERIOD'
[69]  ' '
[70]  ' T-72  AT-5  NUC'
[71]  ' '
[72]  XB
[73]  ' '
[74]  ' RED ATTRITION DURING PERIOD'
[75]  ' '
[76]  ' M1 M2 NUC'
[77]  ' '
[78]  XR
[79]  ' '
[80]  'NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD'
[81]  ' '
[82]  ' T-72 AT-5 NUC'
[83]  ' '
[84]  RDR
[85]  'NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD'
[86]  ' '
[87]  ' M1 M2  NUC'
[88]  ' '
[89]  RDB
[90]  ' '
[91]  ' OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY'
[92]  ' '
[93]  ' SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.'
[94]  '  '
[95]  ' T-72 AT-5 NUC'
[96]  ' '
[97]  PKB
[98]  ' '
[99]  'SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.'
[100] ' '
[101] ' M1 M2 NUC'
[102] ' '
[103] PKR
[104] ' '
[105] 'NUMBER OF I KILLED BY EACH J IN K '
[106] ' '
[107] ' T-72 AT-5 NUC'
[108] ' '
[109] A
[110] '  '
[111] 'NUMBER OF J KILLED BY EACH I IN K.'
[112] ' '
[113] ' M1 M2 NUC'
[114] ' '
[115] B
[116] ' '
[117] ' AVALIBILITY OF BLUE'
[118] ' '
[119] AVALB
[120] ' '
[121] 'AVALIBILITY OF RED'
[122] ' '
[123] AVALR
[124] ' '
[125] ' COMPUTE END RESULTS OF BATTLE'
[126] ' '
[127] ' BLUE FORCE SIZE '
[128] ' '
```

```
[129] 'M1 M2 NUC'
[130] ' '
[131] BL←BL-(+/XB)
[132] BL
[133] ' '
[134] 'RED FORCE SIZE '
[135] ' '
[136] 'T-72 AT-5  NUC'
[137] ' '
[138] R←R-(+/XR)
[139] R
      ∇
      ∇ATCAL
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 3 VALUES
⎕:
      41 85 1
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 3 VALUES
⎕:
      39 85 1
PLEASE ENTER BLUE ATTRITION DURING PERIOD,  9 VALUES
⎕:
      0 0 11 0 0 20 0 0 0
PLEASE ENTER RED ATTRITION DURING PERIOD,  9 VALUES
⎕:
      3 1 0 4 1 0 0 0 0
PLEASE ENTER RED FIRING MATRIX FOR PERIOD,  9 VALUES
⎕:
      0 0 1 0 0 1 0 0 1
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD,  9 VALUES
⎕:
      5 3 0 6 5 0 0 0 0
PLEASE ENTER TIME STEP IN HOURS
⎕:
      1
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
41 85 1
 M1  M2  NUC
INITIAL RED FORCE SIZE
  T-72  AT-5  NUC
39 85 1
 BLUE ATTRITION DURING PERIOD
 T-72   AT-5   NUC
  0  0 11
  0  0 20
  0  0  0
 RED ATTRITION DURING PERIOD
  M1  M2  NUC
 3 1 0
 4 1 0
 0 0 0
NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD
 T-72 AT-5 NUC
 0 0 1
 0 0 1
 0 0 1
NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD
  M1  M2   NUC
 5 3 0
 6 5 0
```

```
 0 0 0
 OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY
 SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.
  T-72 AT-5 NUC
  1 1 11
  1 1 20
  1 1 0
SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.
 M1  M2  NUC
 0.6      0.3333333333 1
 0.6666666667 0.2      1
 1       1       1
NUMBER OF I KILLED BY EACH J IN K
  T-72 AT-5 NUC
  0 0 11
  0 0 20
  0 0 0
NUMBER OF J KILLED BY EACH I IN K.
 M1  M2  NUC
 0.07317073171 0.01176470588 0
 0.09756097561 0.01176470588 0
 0       0       0
 AVALIBILITY OF BLUE
0.000 0.00000.0000
AVALIBILITY OF RED
0.012 0.079 0
 COMPUTE END RESULTS OF BATTLE
 BLUE FORCE SIZE
 M1  M2  NUC
30 65 1
 RED FORCE SIZE
 T-72 AT-5  NUC
35 80 1
      ATCAL
PLEASE ENTER INITIAL BLUE FORCE BY WEAPON SYSTEM, 3 VALUES
⎕:
      30 65 1
PLEASE ENTER INITIAL RED FORCE BY WEAPON SYSTEM, 3 VALUES
⎕:
      35 80 1
PLEASE ENTER BLUE ATTRITION DURING PERIOD,  9 VALUES
⎕:
      5 5 0 4 1 0 0 0 0
PLEASE ENTER RED ATTRITION DURING PERIOD,  9 VALUES
6 6 0 5 2 0 0 0 0
⎕:
PLEASE ENTER RED FIRING MATRIX FOR PERIOD,  9 VALUES
⎕:
      25 25 0 12 4 0 0 0 0
PLEASE ENTER BLUE FIRING MATRIX FOR PERIOD,  9 VALUES
⎕:
      36 36 0 5 8 0 0 0 0
PLEASE ENTER TIME STEP IN HOURS
⎕:
      3
 INPUTS INTO ATCAL FROM VIC
INITIAL BLUE FORCE SIZE
```

30 65 1

M1 M2 NUC

INITIAL RED FORCE SIZE

T-72 AT-5 NUC

35 80 1

BLUE ATTRITION DURING PERIOD

T-72 AT-5 NUC

5 5 0
4 1 0
0 0 0

RED ATTRITION DURING PERIOD

M1 M2 NUC

6 6 0
5 2 0
0 0 0

NUMBER OF ROUNDS FIRED AT BLUE SYSTEMS BY RED SYSTEMS IN PERIOD

T-72 AT-5 NUC

25 25 0
12 4 0
0 0 0

NUMBER OF ROUNDS FIRED AT RED SYSTEMS BY BLUE SYSTEMS IN PERIOD

M1 M2 NUC

36 36 0
5 8 0
0 0 0

OUTPUTS: PROBABILITY OF KILL, ATTRITION RATE, AND AVAILABILITY

SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED AT I BY ONE J IN K.

T-72 AT-5 NUC

0.2 0.2 1
0.3333333333 0.25 1
1 1 1

SINGLE SHOT PROBABILITY FOR EACH ROUND FIRED BY J BY ONE I IN K.

M1 M2 NUC

0.1666666667 0.1666666667 1
1 0.25 1
1 1 1

NUMBER OF I KILLED BY EACH J IN K

T-72 AT-5 NUC

0.04761904762 0.02083333333 0
0.0380952381 0.004166666667 0
0 0 0

NUMBER OF J KILLED BY EACH I IN K.

M1 M2 NUC

0.06666666667 0.03076923077 0
0.05555555556 0.01025641026 0
0 0 0

AVALIBILITY OF BLUE

0.015 0.008 0

AVALIBILITY OF RED

0.012 0.008 0

COMPUTE END RESULTS OF BATTLE

BLUE FORCE SIZE

```
 M1 M2 NUC
20 60 1
 RED FORCE SIZE
 T-72 AT-5  NUC
23 73 1
```

APPENDIX F

REMAINING ATCAL VARIABLES AND PARAMETERS FOR THREE CASES

TABLE 8

ATCAL VARIABLES AND PARAMETERS FOR AT-5 VS M1 IN CASE 1

	INPUTS			OUTPUTS		
Time steps	X	RD	P	A	AV	BL
00 - 12	5	14	.36	.004	.018	30
00 - 06	2.5	7	.36	.004	.014	39.92
06 - 12	2.5	7	.36	.004	.018	29.84
00 - 04	1.67	4.7	.36	.004	.013	43.26
04 - 08	1.67	4.7	.36	.004	.015	36.53
08 - 12	1.67	4.7	.36	.005	.018	29.80
00 - 02	.83	2.3	.36	.004	.012	46.65
02 - 04	.83	2.3	.36	.004	.013	43.30
04 - 06	.83	2.3	.36	.004	.014	39.95
06 - 08	.83	2.3	.36	.004	.015	36.60
08 - 10	.83	2.3	.36	.005	.017	33.26
10 - 12	.83	2.4	.36	.005	.018	29.91

TABLE 9

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M2 IN CASE 1

	INPUTS			OUTPUTS		
Time steps	X	RD	P	A	AV	BL
00 - 12	25	100	.25	.042	.007	65
00 - 06	12.5	50	.25	.042	.006	82.34
06 - 12	12.5	50	.25	.049	.007	64.68
00 - 04	8.33	33.3	.25	.042	.006	88.23
04 - 08	8.33	33.3	.25	.046	.007	76.47
08 - 12	8.33	33.3	.25	.052	.008	64.70
00 - 02	4.17	16.7	.25	.042	.005	94.10
02 - 04	4.17	16.7	.25	.044	.006	88.21
04 - 06	4.17	16.7	.25	.046	.006	82.32
06 - 08	4.17	16.7	.25	.049	.007	76.42
08 - 10	4.17	16.7	.25	.052	.007	70.53
10 - 12	4.17	16.7	.25	.055	.008	64.63

TABLE 10

ATCAL VARIABLES AND PARAMETERS FOR AT-5 VS M2 IN CASE 1

	INPUTS			OUTPUTS		
Time steps	X	RD	P	A	AV	BL
00 - 12	10	24	.43	.009	.007	65
00 - 06	5	12	.43	.009	.006	82.34
06 - 12	5	12	.43	.009	.007	64.68
00 - 04	3.33	8	.43	.009	.006	88.23
04 - 08	3.33	8	.43	.009	.007	76.47
08 - 12	3.33	8	.43	.010	.008	64.70
00 - 02	1.67	4	.43	.009	.005	94.10
02 - 04	1.67	4	.43	.009	.006	88.21
04 - 06	1.67	4	.43	.009	.006	82.32
06 - 08	1.67	4	.43	.009	.007	76.42
08 - 10	1.67	4	.43	.010	.007	70.52
10 - 12	1.67	4	.43	.010	.008	64.63

TABLE 11

ATCAL VARIABLES AND PARAMETERS FOR AT-5 VS M1 IN CASE 2

Time steps	X	RD	P	A	AV	BL
00 - 12	5	14	.36	.004	.018	30
**						
SCENARIO 1 :						
Meeting Engagement						
00 - 02	1	4	.25	.005	.004	48
static Defense						
02 - 10	3	7	.43	.004	.016	34
Defense						
10 - 12	1	3	.33	.004	.018	30
**						
SCENARIO 2 :						
Meeting Engagement						
00 - 04	1	3	.33	.003	.013	46
static defense						
04 - 08	1	3	.33	.003	.016	41
attack						
08 - 12	3	8	.375	.008	.014	30

TABLE 12

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M2 IN CASE 2

Time steps	X	RD	P	A	AV	BL
00 - 12	25	100	.25	.042	.007	65
**						
SCENARIO 1 :						
Meeting Engagement						
00 - 02	2	10	.20	.020	.005	97
static Defense						
02 - 10	18	65	.28	.049	.007	72
Defense						
10 - 12	5	25	.20	.065	.008	65
**						
SCENARIO 2 :						
Meeting Engagement						
00 - 04	5	25	.20	.025	.006	93
static defense						
04 - 08	5	20	.25	.028	.005	85
attack						
08 - 12	15	55	.27	.095	.007	65

TABLE 13

ATCAL VARIABLES AND PARAMETERS FOR AT-5 VS M2 IN CASE 2

Time steps	X	RD	P	A	AV	BL
00 - 12	10	24	.43	.008	.007	65
*****						
SCENARIO 1 :						
Meeting Engagement						
00 - 02	1	3	.33	.005	.005	97
static Defense						
02 - 10	7	14	.50	.009	.007	72
Defense						
10 - 12	2	6	.33	.010	.008	65
*****						
SCENARIO 2 :						
Meeting Engagement						
00 - 04	2	6	.33	.005	.006	93
static defense						
04 - 08	3	8	.375	.008	.005	85
attack						
08 - 12	5	9	.55	.015	.007	65

TABLE 14

ATCAL VARIABLES AND PARAMETERS FOR AT-5 VS M1 IN CASE 3

Time steps	X	RD	P	A	AV	BL
Meeting Engagement						
00 - 04	1	3	.33	.003	.013	46
Static Defense						
04 - 08	1	3	.33	.003	.016	41
Red NUCLEAR Attack						
08 - 09	0	0	.00	.00	.000	30
Blue Defense						
09 - 12	5	25	.20	.047	.015	20

TABLE 15

ATCAL VARIABLES AND PARAMETERS FOR T-72 VS M2 IN CASE 3

Time steps	X	RD	P	A	AV	BL
Meeting Engagement						
00 - 04	5	25	.20	.025	.006	93
Static Defense						
04 - 08	5	20	.25	.028	.005	85
Red NUCLEAR Attack						
08 - 09	0	0	.00	.00	.000	65
Blue Defense						
09 - 12	5	25	.20	.047	.008	55

TABLE 16

ATCAL VARIABLES AND PARAMETERS FOR AT-5 VS M2 IN CASE 3

Time steps	X	RD	P	A	AV	BL
Meeting Engagement						
00 - 04	2	6	.33	.005	.006	93
Static Defense						
04 - 08	3	8	.375	.008	.005	85
Red NUCLEAR Attack						
08 - 09	0	0	.00	.00	.000	65
Blue Defense						
09 - 12	5	25	.20	.047	.008	55

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